Farming the Future: Review of Agricultural Extension's Role in Digital and Smart Farming Technologies in Davao Oriental, Philippines

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ABSTRACT

Digital and smart farming technologies—ranging from mobile-based advisories and automated irrigation to IoT sensors and data analytics—are transforming global agriculture. In the Philippines, national initiatives such as the Philippine Digital Agriculture Strategy (PDAS) aim to localize these innovations. However, uptake remains limited in rural provinces like Davao Oriental due to weak extension capacity, infrastructure gaps, and fragmented governance. This review investigates the evolving role of agricultural extension in supporting the adoption and diffusion of these technologies in Davao Oriental. Using a structured narrative review methodology, the study applied thematic coding and synthesis across 58 sources, including peer-reviewed literature, government policies, and institutional reports. Key themes include barriers to technology adoption, the role of SUCs and cooperatives, digital literacy, and policy alignment. Findings reveal a mismatch between innovation supply and grassroots readiness, compounded by institutional capacity gaps. The review proposes a policy and institutional roadmap to reimagine extension services as digitally empowered systems. This work offers actionable insights for policymakers, SUCs, and development stakeholders aiming to foster inclusive and resilient digital agriculture at the provincial level.

Keywords: Agricultural Extension, Davao Oriental, Digital and Smart Farming Technologies, Innovation, Technology Adoption, Technology Diffusion

INTRODUCTION

The global shift toward digital and smart farming is revolutionizing how agricultural systems function, offering innovative solutions to long-standing issues such as inefficiencies in crop management, environmental risks, and market volatility. Technologies like precision farming, mobile applications, drone surveillance, and AI-based tools are being deployed to support farmers in making data-driven decisions, improve yields, and ensure resource sustainability (Wolfert et al., 2017). In the Philippines, where agriculture employs about one-fourth of the labor force and underpins food security, digital transformation is recognized as a national priority, as reflected in the Philippine Digital Agriculture Strategy 2021–2025 (DA & IRRI, 2021).

Yet, despite national support, the practical adoption of smart farming tools remains limited in rural provinces like Davao Oriental. Local farming communities face persistent challenges such as low digital literacy, inadequate infrastructure, limited financing, and weak extension systems (Fabregas et al., 2019; NEDA XI, 2022). These gaps are particularly concerning given that agricultural extension is intended to serve as the link between innovation and practice. In many cases, extension workers are expected to promote digital tools without adequate training, resources, or policy support, resulting in a widening technology gap at the farm level.

This review aims to critically examine the role of agricultural extension in facilitating the adoption and diffusion of digital and smart farming technologies in Davao Oriental. It addresses the central research question: How can agricultural extension services in Davao Oriental evolve to effectively support inclusive digital transformation in agriculture? The article synthesizes findings from both academic and institutional sources, exploring the interaction between extension agencies, State Universities and Colleges (SUCs), cooperatives, NGOs, and the private sector. It assesses the institutional capacity, policy environment, and infrastructure readiness necessary to build a resilient and digitally capable extension system.

The study is timely given the increasing urgency to modernize agriculture in response to climate change, food insecurity, and rural poverty. Davao Oriental, with its diverse topography and predominantly agri-based economy, serves as a critical case study for understanding the challenges and opportunities of digital agriculture in a localized, under-resourced setting. Although several pilot projects involving automated irrigation, mobile pest alerts, and climate-resilient systems have emerged, these efforts are often fragmented and poorly integrated into mainstream extension programs (DOrSU, 2022; Klerkx et al., 2019).

This review contributes to the broader discourse on digital transformation in agriculture by contextualizing it within the governance, institutional, and socio-technical realities of a rural Philippine province. It proposes actionable pathways for reforming extension policy and practice, drawing lessons that are applicable not only to Davao Oriental but also to other underserved agricultural regions in the Philippines and Southeast Asia.

METHODOLOGY

This review article employed a narrative and thematic literature review methodology to synthesize scholarly and institutional knowledge on the role of agricultural extension in supporting digital and smart farming innovation in the province of Davao Oriental. The review focused on published peer-reviewed journals, policy documents, program reports, and institutional publications from 2000 to 2023. Databases such as Scopus, Google Scholar, ScienceDirect, and Philippine e-Journals were used to gather literature using search terms including: "agricultural extension," "Davao Oriental," "digital agriculture," "smart farming technologies," "technology adoption," and "technology diffusion." The inclusion criteria prioritized studies that discussed rural and regional implementation of smart farming practices, particularly within Philippine or Southeast Asian contexts (Snyder, 2019).

The selected literature was thematically analyzed and organized into key sub-topics aligned with the article's research focus: institutional roles of extension agencies, technology adoption barriers, ICT-supported services, innovation ecosystems involving SUCs, cooperatives, and NGOs, and relevant policy frameworks. The analysis emphasized both enablers and constraints of technology diffusion in local agricultural systems, particularly in upland and coastal communities of Davao Oriental. Grey literature, such as reports from the Department of Agriculture (DA), Davao Oriental State University (DOrSU), and NEDA XI, were also included to capture recent developments, localized programs, and pilot projects not covered in academic databases (Booth et al., 2016).

The review adopted a contextual lens, situating the findings within the socio-economic, agro-ecological, and institutional realities of Davao Oriental. This approach allowed for the identification of localized gaps and opportunities in extension practices and their responsiveness to emerging digital and smart farming technologies. Furthermore, the methodology integrated a policy analysis component to examine the alignment between national digital agriculture programs and local extension implementation. This comprehensive and context-driven method provides a foundation for assessing how agricultural extension can accelerate

technology adoption and diffusion in Davao Oriental, ensuring that smart farming innovations are accessible, inclusive, and sustainable (Petticrew & Roberts, 2006).

DISCUSSIONS

Davao Oriental: A Provincial Profile

Davao Oriental, located in the southeasternmost part of the Philippines, is the eastern gateway of Mindanao. It is bounded by the Pacific Ocean to the east, Compostela Valley (now Davao de Oro) to the west, Agusan del Sur and Surigao del Sur to the north, and Davao Gulf to the south. The province covers a total land area of approximately 5,679.64 square kilometers and comprises 10 municipalities and one city, which is also the capital—City of Mati (Philippine Statistics Authority [PSA], 2022). Its topography includes vast coastal areas, mountain ranges, and fertile lowlands, making it highly suitable for agriculture, forestry, and marine resources development.

Agriculture is the backbone of Davao Oriental's economy. The province is a major producer of coconut, abaca, banana, rice, and corn. Coconut farming dominates the agricultural landscape, with over 100,000 hectares planted to coconut, making Davao Oriental a leading coconut-producing province in the country (Department of Agriculture [DA], 2023). Other high-value crops and industrial crops such as cacao, coffee, and rubber are also cultivated in various parts of the province. Livestock, poultry, and fisheries are secondary but important components of the agri-based economy, especially in coastal and upland areas.

In terms of development, Davao Oriental is part of the Davao Region (Region XI) and is included in regional and national development initiatives focusing on inclusive and sustainable growth. The province actively participates in the implementation of the Philippine Development Plan (PDP) and the Regional Development Plan (RDP), particularly in agriculture, ecotourism, disaster resilience, and digital transformation (National Economic and Development Authority [NEDA], 2023). It is also a beneficiary of various support programs under the Department of Science and Technology (DOST), the Department of Agrarian Reform (DAR), and the Department of Agriculture (DA), which aim to enhance productivity and sustainability in agriculture.

Davao Oriental is also notable for its strong commitment to environmental protection and biodiversity conservation. It is home to Mount Hamiguitan Range Wildlife Sanctuary, a UNESCO World Heritage Site, which showcases unique flora and fauna and endemic species (UNESCO, 2022). The province has integrated eco-agriculture and environmental protection into its local development plans, promoting agroforestry, organic farming, and climate-smart agriculture. These initiatives are complemented by the province's efforts to integrate technology and innovation into extension services and agribusiness models, often in collaboration with state universities and colleges such as Davao Oriental State University.

Overall, Davao Oriental stands as a province rich in natural resources, agricultural potential, and cultural heritage. As it continues to embrace innovation and sustainability, particularly in the agricultural sector, it presents an important case for examining the role of agricultural extension in facilitating digital and smart farming technologies. With the convergence of strong local governance, institutional support, and growing interest in sustainable agribusiness, Davao Oriental offers a dynamic context for research and development in agricultural innovation and circular economy strategies.

Overview of Agricultural Extension in Davao Oriental

Agricultural extension in Davao Oriental has evolved alongside the changing paradigms of agricultural development in the Philippines. Historically, extension work in the province was rooted in traditional, production-oriented methods aligned with the national push for food sufficiency, particularly during the Green Revolution era (David, 2003). This approach heavily relied on top-down transfer of technology (TOT) models where agricultural technicians disseminated pre-packaged solutions to farmers. However, this method often overlooked the contextual realities of smallholders in upland, coastal, and indigenous communities—common in Davao Oriental—leading to low adoption rates and unsustainable practices (Palis et al., 2015). This

historical backdrop underscores the need for more participatory and adaptive extension frameworks, especially in transitioning toward smart and digital agriculture.

Institutionally, Davao Oriental's extension system operates under a decentralized setup. The Provincial Agriculture Office (PAGRO) oversees province-wide programs and serves as a coordinating body with the City and Municipal Agriculture Offices (C/MAGROs), which are directly in charge of delivering services to local farming communities. These agencies are crucial actors in disseminating production technologies, providing livelihood support, and facilitating access to resources such as seeds, fertilizers, and technical training. However, despite their key role, many LGU-based extension offices remain under-resourced and understaffed, hindering the delivery of timely and tailored extension services (Lamban et al., 2017). This limitation has significant implications for the article, as it highlights a bottleneck in integrating and scaling digital and smart technologies in farming practices across the province.

In recent years, State Universities and Colleges (SUCs), particularly Davao Oriental State University (DOrSU), have emerged as critical players in research-based and community-anchored extension. DOrSU, through its RDE (Research, Development, and Extension) programs, has implemented initiatives such as sustainable coconut farming, integrated pest management, and climate-resilient agriculture. These initiatives often incorporate ICT tools for information dissemination, such as mobile advisories and social media-based farmer groups (DOrSU, 2022). The increasing collaboration between SUCs and LGUs reflects a shift toward more holistic and knowledge-based extension models. The implication to the article is clear: SUCs can serve as innovation hubs that help bridge gaps between traditional extension and emerging smart agriculture platforms.

Moreover, the province has adopted a variety of extension modalities such as Farmer Field Schools (FFS), Learning Sites for Agriculture (LSAs), and demonstration farms, which emphasize experiential learning and farmer-to-farmer knowledge exchange. These platforms create opportunities for participatory learning and social capital development, which are essential prerequisites for digital transformation in agriculture (Rola et al., 2018). For instance, farmers trained in FFS are more likely to embrace technological innovations due to their exposure to scientific approaches and collaborative problem-solving. This finding supports the article's thesis that agricultural extension, when strengthened and contextualized, can be a vehicle for the adoption of smart and digital farming technologies.

However, literature also points to a critical gap: the limited incorporation of digital tools in these traditional modalities. Many LSAs and demo farms in Davao Oriental still focus on organic farming, crop diversification, or ecological practices without leveraging ICT-enabled monitoring systems, mobile applications, or geospatial analytics. While these models are effective in promoting sustainable agriculture, their lack of digital integration poses a challenge to aligning provincial extension with national and global digital agriculture agendas (Aregu et al., 2020). The article must therefore explore how these traditional extension structures can evolve into hybrid models that blend indigenous knowledge with digital innovations to enhance precision, efficiency, and resilience in farming systems.

The literature on agricultural extension in Davao Oriental reveals a strong institutional foundation and a rich history of participatory extension models. However, the transition to digital and smart agriculture requires both systemic and structural shifts—from enhancing the capacity of LGU extension workers to investing in ICT infrastructure and strengthening partnerships with SUCs. The implication for this review article is to identify not only the strengths of the existing extension system but also its readiness and adaptability to serve as a conduit for digital innovation. This foundational understanding is necessary to map the trajectory of agricultural modernization in Davao Oriental and similar rural contexts.

Digital and Smart Farming Technologies: Global Trends and Local Relevance

Digital agriculture, also known as smart farming, is reshaping global agricultural systems through the integration of emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), remote sensing, drone technology, and big data analytics (Wolfert et al., 2017). These tools enhance precision in crop production, optimize resource use, and support real-time decision-making for farmers. For instance, drone-assisted imaging enables detailed monitoring of crop health, while IoT sensors offer continuous data on soil

moisture and nutrient levels (Rose et al., 2018). As global agriculture confronts climate change, labor shortages, and food security demands, digital innovations are increasingly being positioned as necessary solutions. The implication for the article is that Davao Oriental, while largely rural, cannot remain isolated from these shifts if it aims to modernize and build resilient agri-food systems.

The integration of digital technologies into Philippine agriculture has been gaining traction through national programs such as the Department of Agriculture's (DA) "Digital Agriculture Roadmap 2020–2025," which outlines goals for integrating ICT tools in farming, market access, and extension delivery (Department of Agriculture, 2020). However, the uptake remains uneven, especially in geographically isolated and disadvantaged areas (GIDAs) like parts of Davao Oriental. Connectivity issues, high costs of digital tools, and limited digital literacy among farmers have hindered widespread adoption (Lamban et al., 2017). These barriers emphasize the role of agricultural extension as a mediating force—not only for technology diffusion but also for capability building. Thus, the literature underlines the article's argument that extension must evolve to become digitally empowered and farmer-centered to serve as a bridge between innovation and inclusion.

The relevance of smart farming tools in Davao Oriental's diverse agro-climatic zones is a crucial consideration. The province consists of coastal plains, mountainous terrains, and upland rain-fed areas, each requiring different agricultural strategies. For instance, precision irrigation and automated pest monitoring could be useful in coconut and banana plantations, while remote sensing tools may enhance crop suitability mapping in upland zones (DOrSU, 2022). However, the adaptability of these tools depends on localized calibration, farmer training, and contextual knowledge of environmental patterns (Strobel et al., 2020). This implies that agricultural extension in the province must be equipped not only with technical knowledge but also with contextual insights to guide the appropriate selection and scaling of technologies.

Critically, while much of the discourse on smart farming is technology-driven, several scholars caution against a techno-centric approach. According to Klerkx et al. (2019), focusing solely on technology without addressing social, institutional, and infrastructural readiness can result in digital divides that further marginalize smallholders. This critique is especially pertinent to Davao Oriental, where many farmers belong to vulnerable sectors such as indigenous groups and small-scale fisherfolk. Therefore, the review article must frame digital agriculture within a broader framework of equity, capacity-building, and participatory governance, ensuring that technological advancement does not reinforce existing disparities.

Several pilot initiatives in the Philippines, such as the Smart Agriculture Program by PhilRice and ICT-based pest surveillance systems by IRRI, have demonstrated the potential for scalable digital interventions (PhilRice, 2021). However, evidence from similar programs in Mindanao remains sparse. The absence of localized documentation on smart farming adoption in Davao Oriental underscores the need for empirical studies and participatory action research. Agricultural extension institutions, especially Davao Oriental State University and local government units, are well-positioned to lead these localized efforts. This highlights the article's contribution in identifying key gaps in both research and implementation, which must be addressed for sustainable digital agriculture to take root in the province.

The global literature on digital agriculture underscores a strong potential for transformative impacts, but also reveals the contextual limitations of adopting a one-size-fits-all approach. For Davao Oriental, these technologies must be aligned with local farming systems, terrain-specific challenges, and socio-economic conditions. The literature suggests that agricultural extension systems need to evolve into digitally capable, knowledge-intensive, and inclusive platforms that empower farmers. Therefore, this review article aims to map not only the technological trends but also the enabling conditions and strategic entry points for effective digital transformation through extension services in the province.

Current Status and Challenges of Technology Adoption among Farmers in Davao Oriental

Digital readiness among farmers in rural areas, including Davao Oriental, remains a critical determinant of the success of smart farming initiatives. Digital literacy, defined as the ability to access, understand, and use digital tools, is still relatively low among smallholder farmers in the province, particularly in upland and coastal

communities (Lamban et al., 2017). Although mobile phone ownership is widespread, the usage is largely limited to basic communication, with minimal engagement in agricultural applications, e-commerce platforms, or data-based decision-making. This implies that digital agriculture cannot be introduced without simultaneous efforts in digital literacy and capacity building. Therefore, the article must emphasize the centrality of agricultural extension services in promoting digital literacy alongside technological dissemination.

Another major factor affecting the adoption of smart farming technologies is the limited access to infrastructure, particularly reliable internet and mobile connectivity. In Davao Oriental, several barangays remain underserved by digital infrastructure due to their geographic remoteness and low population density (NEDA XI, 2022). As such, the technological gap is not merely a result of farmers' unwillingness to adopt innovations, but of structural exclusion that limits their options. This digital divide challenges the feasibility of implementing ICT-based extension models and precision agriculture tools in these areas. The implication for the article is the need to explore hybrid models of extension—combining traditional face-to-face approaches with low-bandwidth, SMS-based, or offline-capable technologies—to ensure inclusive technology dissemination.

Cost is also a significant barrier to smart farming adoption among resource-constrained farmers. Advanced technologies such as drones, IoT sensors, and automated systems often come at a high cost, which is prohibitive for smallholder farmers who operate on limited capital (Aregu et al., 2020). Moreover, the lack of financial literacy and access to financing programs limits the capacity of farmers to invest in digital tools. This constraint suggests that technology promotion efforts must be accompanied by financial support mechanisms, such as government subsidies, public-private partnerships, or cooperatives that pool resources for collective access to innovation. This aligns with the article's perspective that agricultural extension must also take on a facilitative role in linking farmers to financial instruments that enable technological adoption.

Socio-cultural perceptions also play a role in shaping adoption behavior. Farmers, especially those from older generations, may be skeptical of modern tools, viewing them as either unreliable or incompatible with their farming practices (Rola et al., 2018). There is often a preference for traditional knowledge and methods that have proven effective over decades. This generational divide presents a psychological barrier that must be addressed through culturally sensitive and experiential learning approaches, such as demo farms and farmer-led experimentation. The implication to the article is that the extension agents must not only be technology promoters but also change managers who build trust and engagement through gradual, inclusive learning processes.

Capacity-building remains a recurring theme in the literature, with several scholars pointing to the shortage of well-trained extension workers capable of facilitating digital transformation in rural agriculture. In Davao Oriental, LGU-based extension staff often lack access to continuous professional development and digital training (David, 2003). This results in a situation where extension agents themselves are unprepared to guide farmers in adopting new technologies. The article, therefore, must consider capacity development of extension personnel as a prerequisite for effective digital extension. It also raises the question of institutional collaboration—how SUCs like Davao Oriental State University can support LGUs in enhancing extension capacity through targeted training and resource-sharing.

The current literature underscores the multidimensional challenges facing technology adoption among farmers in Davao Oriental. These include low digital literacy, inadequate infrastructure, cost barriers, cultural perceptions, and institutional capacity gaps. Each of these challenges has profound implications for how agricultural extension is designed and delivered. This article contributes by critically analyzing how extension systems in Davao Oriental can be reimagined to respond to these challenges—not only as transmitters of technology, but as enablers of readiness, inclusion, and innovation. Addressing these barriers holistically is essential to realizing the transformative potential of digital and smart farming technologies in the province**.**

Role of Extension Services in Promoting Digital Literacy and Technology Transfer

Extension services have long been positioned as intermediaries in the transfer of agricultural innovations, but their role is evolving rapidly in the digital age. As digital tools and smart technologies reshape agricultural

production and management, extension agents are increasingly expected to act as change agents for digital transformation (Rivera & Sulaiman, 2009). This means not only delivering new knowledge but also facilitating mindset shifts, digital skill acquisition, and farmer engagement with emerging technologies. In the context of Davao Oriental, where farming populations are diverse and often underserved, this expanded role is particularly critical. The implication for this article is clear: the effectiveness of digital agriculture will depend heavily on how well extension services are able to retool and reposition themselves as digitally competent facilitators.

Studies show that extension workers' digital competencies directly influence farmers' adoption of smart technologies. However, many local extension workers in the Philippines, including those in Davao Oriental, lack formal training in digital tools, apps, and ICT-enabled platforms (Lamban et al., 2017). This capacity gap undermines the potential of extension to function as a bridge between technological innovation and practical application. For example, without familiarity with precision farming apps or remote sensing tools, extension workers are unlikely to recommend or demonstrate their use to farmers. This observation supports the argument that digital literacy among extension agents is not a luxury but a prerequisite for scalable technology transfer in the agricultural sector.

In response to this gap, several ICT-supported extension services have emerged in the Philippines, offering alternative and complementary platforms for information dissemination. These include text blast advisories, Facebook groups, and mobile-based advisory systems such as the Rice Crop Manager and e-Damuhan (PhilRice, 2021). In Davao Oriental, anecdotal reports suggest that LGUs and SUCs such as Davao Oriental State University are beginning to use social media and messaging platforms to engage farmers, especially during typhoon alerts or crop management advisories. These efforts indicate a promising shift toward blended extension models. However, literature warns that digital platforms should not replace face-to-face engagement but should augment traditional methods to ensure inclusivity and contextual relevance (Fabregas et al., 2019). For the review article, this suggests that technology transfer is not just about tools—it is about relationships, communication styles, and trust-building.

The effectiveness of digital extension services also depends on their design and delivery, particularly in user-friendliness, local language use, and cultural appropriateness. A study by Rose et al. (2018) highlights that poorly designed digital tools often discourage user uptake and lead to abandonment, even when access is provided. In Davao Oriental, this is especially relevant given the linguistic diversity and varying literacy levels of farmers across municipalities. Extension services must therefore go beyond just distributing information and focus on co-creating solutions with farmers, ensuring that content is understandable, contextually relevant, and easily accessible. This implies that digital literacy must be embedded in broader capacity-building frameworks, not treated as a standalone activity.

From a policy and institutional standpoint, the lack of a structured training program for extension agents in digital skills remains a bottleneck. While the Department of Agriculture and ATI (Agricultural Training Institute) have launched initiatives like the e-Extension platform, participation among LGU-based extension workers in remote provinces like Davao Oriental remains limited (ATI, 2022). This suggests that national programs must prioritize decentralization and resource targeting to ensure remote provinces are not left behind. The review article, therefore, should advocate for institutional reforms and localized strategies that empower extension workers as frontline actors in digital agriculture.

The literature underscores the pivotal role of extension services in enabling digital agriculture, especially in contexts like Davao Oriental where challenges in literacy, infrastructure, and trust coexist. Extension workers must transition from being mere conduits of information to becoming digital mentors, facilitators, and innovation brokers. The implications to the article are multi-dimensional: to understand technology adoption, one must examine the readiness and role of extension services in catalyzing digital transformation. Strengthening these services is not optional—it is essential to farming the future.

Smart Farming Initiatives and Pilot Projects in Davao Oriental

Smart farming initiatives in the Philippines have seen increasing support from national agencies such as the Department of Science and Technology – Philippine Council for Industry, Energy, and Emerging Technology

Research and Development (DOST-PCIEERD) and the Department of Agriculture (DA). These agencies fund and promote projects involving remote sensing, automated irrigation, mobile pest advisories, and decision support systems (DOST-PCIEERD, 2021). In Davao Oriental, however, the implementation of such projects has been limited and largely concentrated in research institutions or pilot communities. The implication for this article is the need to assess not only the availability but also the localization and accessibility of these initiatives, which is critical for scaling up digital agriculture in rural, resource-constrained areas.

Among the notable efforts is the involvement of Davao Oriental State University (DOrSU) in implementing localized agricultural technology solutions. DOrSU's research and development projects in collaboration with DA and LGUs have included the use of mobile applications for pest identification and advisories, as well as small-scale precision irrigation systems using sensor technologies (DOrSU, 2022). These pilot projects demonstrate the potential of SUCs to serve as innovation hubs and knowledge incubators for smart farming. However, their impact is often constrained by funding cycles, limited farmer reach, and gaps in extension integration. The article should emphasize the importance of institutionalizing university-led innovations into broader agricultural extension systems to ensure continuity and farmer adoption beyond the pilot stage.

Despite the presence of national frameworks promoting smart agriculture, such as DA's "Agri 4.0" roadmap and the Smart Agriculture Program, local adoption in provinces like Davao Oriental remains slow (Department of Agriculture, 2020). One of the barriers identified in literature is the lack of systematic monitoring and evaluation of pilot projects, which results in limited feedback mechanisms and scalability assessments (Aregu et al., 2020). Additionally, the absence of strong public-private partnerships in these initiatives reduces the potential for sustainable technology deployment. These issues imply that future extension efforts must include M&E components and multi-stakeholder collaboration to facilitate adaptive learning and investment mobilization.

Moreover, pilot projects often fail to integrate local knowledge systems and farmer feedback, which are essential for contextualizing technology solutions. Literature points out that many smart farming tools introduced in Southeast Asia lack participatory design, leading to low usability and limited relevance to smallholder needs (Klerkx et al., 2019). In Davao Oriental, similar risks exist when technologies are imported or scaled without adequate user testing and adaptation to the province's diverse agro-climatic zones. The article should argue that successful smart farming initiatives must embrace farmer-led innovation models, where extension agents serve as facilitators of co-creation rather than mere technology transmitters.

Another gap in current smart farming projects is the weak connection between research institutions and local government agricultural offices. While DOrSU and some municipal agriculture offices have started to collaborate, the full potential of this partnership remains untapped due to fragmented planning and resource limitations (Lamban et al., 2017). Strengthening institutional linkages can enable continuous knowledge flow, joint capacity building, and co-management of technologies. The article, therefore, must advocate for structured partnerships among SUCs, LGUs, and farmers' organizations to anchor pilot projects into local development agendas and extension programs.

While Davao Oriental has seen emerging efforts in smart agriculture through DOST and DA-supported initiatives, these remain fragmented, short-term, and underutilized. The literature highlights the need to institutionalize research outputs, enhance local participation, and strengthen multi-level coordination for lasting impact. This article contributes by critically reviewing how extension systems can bridge the gap between pilot initiatives and widespread technology adoption, ensuring that smart farming tools do not remain confined to experimental settings but become part of the province's agricultural mainstream.

Government Policies and Programs Supporting Agri-Digitalization

The Philippine government has recognized digital agriculture as a strategic pathway toward sustainable food systems, rural transformation, and economic competitiveness. The Philippine Digital Agriculture Strategy (PDAS) 2021–2025, developed by the Department of Agriculture (DA) in partnership with the International Rice Research Institute (IRRI), outlines a roadmap for digital integration in agricultural value chains. It emphasizes digital literacy, ICT infrastructure, data analytics, and precision agriculture technologies (DA &

IRRI, 2021). The strategy also calls for strengthening agricultural extension services as facilitators of this transformation. The implication to the article is significant: the digital shift is policy-backed, positioning extension agents as central actors who must not only disseminate innovation but also navigate and implement digital frameworks at the grassroots level.

In addition to PDAS, programs such as the Farm and Fisheries Clustering and Consolidation (F2C2) and Smart Agriculture Program are key enablers of agri-digitalization. F2C2 promotes economies of scale, digital traceability, and centralized access to services, while the Smart Agriculture Program supports the deployment of digital tools such as GIS-based farm planning, remote sensing, and drone applications (Department of Agriculture, 2020). However, a challenge identified in the literature is the misalignment between national policy and localized implementation, particularly in geographically isolated or under-resourced provinces like Davao Oriental (Lamban et al., 2017). This gap underscores the role of extension in contextualizing national programs, aligning them with local capacities, and mediating between policy and practice.

In Region XI, where Davao Oriental belongs, DA XI has piloted several smart agriculture projects aligned with the PDAS and F2C2 objectives. These include digital farmers' registry systems, geotagging of farms, and climate-smart agriculture training modules (DA XI, 2022). However, literature indicates that these interventions remain fragmented, often donor- or project-driven, and lack sustainable funding or institutional embedding. This creates a discontinuity in policy uptake and diminishes long-term impacts. The article must therefore highlight the need for institutional coherence and budgetary support in translating these national directives into functioning, inclusive, and long-term programs on the ground.

A further critical issue is the limited participation of LGUs and SUCs in the co-design of digital agriculture policies. Most national programs are top-down, and their success depends heavily on how local institutions— such as Davao Oriental's Provincial Agriculture Office and Davao Oriental State University—are engaged as co-implementers (Palis et al., 2015). For example, without local data, infrastructure, or human resources, digital tools promoted by PDAS may not fit the needs or capacities of local farmers. This creates a disconnect between policy vision and grassroots realities. Thus, the article must advocate for decentralization and participatory policy design, where extension workers and farmers inform policy based on lived experience.

Moreover, policy documents often lack provisions for monitoring and evaluation (M&E) mechanisms to assess the effectiveness and adaptability of digital tools in varying agro-ecological zones like those found in Davao Oriental. Aregu et al. (2020) argue that such M&E frameworks are essential to recalibrate programs based on evidence and local learning. Without this, technologies risk being underutilized or rejected. Therefore, this article should underscore the importance of feedback loops between farmers, extension agents, and policymakers to ensure that government digital agriculture programs are dynamic, context-responsive, and farmer-inclusive.

While national policies such as PDAS and programs like F2C2 and Smart Agriculture provide a robust policy framework for agri-digitalization, their success hinges on effective localization, institutional coordination, and capacity development. For Davao Oriental, this means that agricultural extension must evolve into a policy-implementing and adaptive learning system capable of translating top-level strategies into community-responsive actions. The article contributes by critically examining how policy environments interact with extension systems to determine the future of digital agriculture in marginalized yet high-potential provinces like Davao Oriental.

Innovation Hubs, SUCs, and R&D Contributions

State Universities and Colleges (SUCs) in the Philippines are increasingly being recognized as innovation hubs that bridge research, education, and community engagement, particularly in agriculture. In Davao Oriental, Davao Oriental State University (DOrSU) serves as a pivotal institution in promoting agricultural development through its research and extension programs. SUCs are not only mandated to conduct R&D but also to engage in community outreach that applies scientific findings to local realities (CHED, 2016). The implication for this article is clear: SUCs like DOrSU have the institutional mandate and proximity to farming communities to be central players in digital agriculture transformation.

DOrSU's Research, Development, and Extension (RDE) programs have increasingly focused on smart and ICT-based agricultural innovations. These include pilot projects on automated irrigation systems, mobile-based pest management advisories, and solar-powered dryers for post-harvest handling (DOrSU, 2022). These initiatives are often funded by national agencies such as the Department of Agriculture (DA), Department of Science and Technology (DOST), and CHED, with DOrSU acting as the implementing academic institution. These technologies, when integrated into local extension systems, offer practical, scalable solutions to farming challenges such as unpredictable rainfall, pest outbreaks, and labor shortages. Therefore, the article must highlight how SUC-led innovations can function as both technology generators and extension platforms.

However, literature reveals that despite the R&D outputs generated by SUCs, their translation into farmer-level adoption remains limited due to weak technology transfer mechanisms and fragmented institutional partnerships (Palis et al., 2015). Innovations often remain at the pilot or experimental stage without being mainstreamed into local agriculture practices. This gap highlights the need for strengthened linkage between SUCs and local extension offices to ensure that research outputs reach the end-users. The implication to the article is that innovation must not be seen as a linear process but as a multi-actor, iterative system where extension plays a facilitative role in refining and scaling technologies.

In terms of infrastructure, DOrSU has established its Technology Transfer and Licensing Office (TTLO) and Innovation and IP Management Office, which serve as platforms for protecting, commercializing, and deploying agricultural technologies (DOrSU, 2022). These institutional mechanisms reflect growing recognition that innovation must be managed not just through R&D, but through structured dissemination, capacity building, and policy engagement. However, these units often operate with limited funding and personnel, making it difficult to expand the reach of ICT-based innovations. As the review article explores the role of extension in smart agriculture, it must also examine how such institutional innovations can be sustained and better supported by national and regional programs.

Moreover, the potential of DOrSU and other SUCs as regional learning centers remains underutilized. According to Rola et al. (2018), SUCs must go beyond project-based engagement and move toward institutionalized, long-term partnerships with LGUs, NGOs, and farmer cooperatives. Embedding smart farming technologies in curriculum, farmer training programs, and extension activities can help normalize their use and increase farmer trust and confidence. The article should argue that SUCs, particularly in rural provinces like Davao Oriental, are uniquely positioned to create a "feedback-rich innovation ecosystem" that connects policy, science, and practice.

The literature affirms the critical role of SUCs like DOrSU in shaping the future of digital agriculture through research, innovation, and community engagement. However, the transformative potential of these institutions depends on their ability to connect R&D with extension, co-design technologies with farmers, and institutionalize innovation processes beyond project timelines. For the article, this means framing agricultural extension not only as a delivery mechanism but as a collaborative system that leverages the intellectual, social, and technological capital of SUCs to advance inclusive and sustainable digital transformation in agriculture.

Farmer Cooperatives and Associations as Platforms for Technology Diffusion

Farmer cooperatives and associations play an essential role in agricultural development, not only in resource pooling and market access but increasingly as platforms for technology diffusion. Globally, studies suggest that cooperatives offer a strategic avenue to introduce digital tools and smart farming practices, as their collective structure facilitates shared learning, peer-to-peer support, and coordinated adoption (Basu et al., 2021). In the Philippine context, including Davao Oriental, cooperatives have been instrumental in mobilizing farmers for government-supported programs, including those involving digital registration, farm mechanization, and training in ICT-based farm management tools. The implication to the article is that these farmer groups can serve as effective entry points for agricultural extension workers to promote and scale digital innovations in a community-centric manner.

In Davao Oriental, several cooperatives and associations have participated in ICT-driven initiatives such as digital crop mapping, online marketing platforms, and SMS-based advisories. One example is the involvement

of coconut farmer associations in mobile-based pest monitoring systems piloted by Davao Oriental State University in partnership with LGUs (DOrSU, 2022). These projects demonstrate the value of collective structures in accelerating technology awareness and experimentation. Cooperative members often serve as early adopters and multipliers, creating ripple effects in their local communities. However, as the literature emphasizes, such success stories are context-dependent and require consistent extension support, technical assistance, and trust-building (Aregu et al., 2020).

Despite these successes, there are notable limitations in cooperative-led tech adoption, particularly in less organized or underfunded groups. Many cooperatives in rural Mindanao, including those in Davao Oriental, struggle with weak leadership, limited digital literacy, and insufficient access to ICT infrastructure (Lamban et al., 2017). These internal challenges inhibit their capacity to absorb and manage new technologies effectively. Moreover, some cooperatives are heavily dependent on external support and lose momentum once funding ends, suggesting a lack of sustainability and ownership. For this article, these limitations highlight the need for capacity-building strategies that strengthen the institutional and digital readiness of cooperatives as long-term partners in smart farming diffusion.

Additionally, digital exclusion remains a challenge even within cooperatives, particularly among older members or those in geographically remote areas. Research shows that while younger, more educated members may readily adopt digital tools, others may feel alienated or overwhelmed by new technologies (Rola et al., 2018). This intra-group digital divide can create resistance or uneven adoption, limiting the overall effectiveness of cooperatives as technology diffusion platforms. Extension services must therefore employ inclusive strategies—such as modular digital literacy training and peer mentoring models—to ensure that all members benefit equally. The article should argue that without this inclusivity, cooperatives may unintentionally widen rather than bridge digital gaps.

From a policy standpoint, national and regional programs such as the Farm and Fisheries Clustering and Consolidation (F2C2) strategy recognize cooperatives as key players in advancing digital agriculture (Department of Agriculture, 2020). However, implementation at the local level remains inconsistent, and many cooperatives are not yet integrated into regional agri-digitalization roadmaps. In Davao Oriental, there is a growing opportunity to align cooperative development initiatives with smart farming strategies through better coordination among DA XI, LGUs, and SUCs like DOrSU. The article should emphasize this potential for synergistic policy alignment and multi-sector collaboration as critical for technology diffusion success.

Farmer cooperatives and associations offer promising avenues for digital tool adoption in agriculture due to their existing organizational frameworks, collective trust, and influence among farmers. However, their effectiveness depends on internal readiness, consistent extension support, and inclusive engagement. For the review article, this means viewing cooperatives not as passive recipients but as active enablers of digital transformation, requiring targeted investments in both technology and organizational capacity. Their role is essential in shaping an extension ecosystem that is participatory, sustainable, and locally anchored in Davao Oriental.

Private Sector and NGO Participation in Digital Extension Services

The private sector and non-governmental organizations (NGOs) are increasingly becoming influential players in the delivery of digital extension services in agriculture. Their participation often addresses gaps in public sector capacity, offering technological innovations, funding, and expertise in areas such as mobile applications, real-time data services, and farmer support systems (Krell et al., 2021). In the context of Davao Oriental, where government resources and ICT infrastructure may be limited, partnerships with agri-tech startups, telecommunications companies, and development NGOs present a strategic opportunity to accelerate the diffusion of smart farming technologies. The implication for the review article is that extension cannot be viewed solely as a public function—it must evolve as a multi-stakeholder ecosystem that includes the private and civil society sectors.

One area where private and NGO involvement has shown promise is in weather forecasting and climate advisory services. For example, platforms like IBM's The Weather Company, CropIn, and local tools

developed in partnership with NGOs provide hyperlocal, timely data that helps farmers make informed decisions about planting, irrigation, and pest control (FAO, 2022). Some of these tools have been piloted in the Philippines through DA-initiated partnerships with telcos like Smart and Globe. However, in rural provinces like Davao Oriental, adoption is uneven due to affordability issues, signal coverage, and limited digital literacy. These challenges suggest that while private sector innovations are technically advanced, they require support from extension agents to facilitate awareness, training, and localized integration into farming practices.

NGOs also play a critical role in bridging the digital divide by co-developing ICT tools with communities. For instance, organizations such as the AsiaDHRRA and Catholic Relief Services have implemented community-based ICT interventions in Mindanao that include mobile soil testing services, GIS mapping for agro-enterprise planning, and farmer profiling tools (AsiaDHRRA, 2021). These efforts often succeed because of their participatory approach, cultural sensitivity, and grounding in community organizing. However, sustainability remains an issue once project funding ends, and there's often a disconnect between these initiatives and mainstream agricultural extension systems. The article should highlight that extension services must not only partner with NGOs but also institutionalize and scale these models through public-sector adoption.

A major opportunity lies in supply chain traceability systems supported by private companies. Traceability apps and blockchain tools developed by agritech firms like AgroDigital and InsightSCS are gaining traction in regions supplying export markets (Klerkx et al., 2019). These tools enhance transparency, ensure compliance with food safety standards, and improve market access for farmers. However, many smallholder farmers in Davao Oriental are unfamiliar with these technologies or excluded from supply chains that use them. This reinforces the need for extension services to advocate for inclusive business models and ensure that digital supply chain tools are adapted to small-scale production systems, not just large agribusinesses.

Nevertheless, one of the limitations of private sector involvement is the risk of commercial bias and data ownership concerns. Farmers may become dependent on proprietary technologies without fully understanding data privacy implications or long-term costs (Rose et al., 2018). NGOs, while more community-oriented, may also be constrained by project cycles that limit long-term impact. The review article must therefore argue for transparent, inclusive, and farmer-centered models of collaboration, where public extension plays a regulatory and facilitative role to balance innovation with ethical considerations.

The literature underscores that private sector and NGO participation is essential to digitalizing agriculture in regions like Davao Oriental. However, these collaborations must be strategically embedded within extension systems to ensure they are sustainable, inclusive, and equitable. For the article, this means advocating for an integrated extension approach—one that mobilizes private innovation, leverages NGO outreach capacity, and ensures alignment with government priorities and local farmer needs. Extension agents must act as mediators, ensuring that technological solutions from these actors are adapted, accessible, and truly serve the interests of smallholder farmers.

Policy and Institutional Recommendations for Strengthening Digital Extension in the Province

Local extension governance in the Philippines operates within a devolved system where municipal and city governments are tasked with delivering agricultural extension services. While this structure allows for localized decision-making, it also creates inconsistencies in policy implementation, funding, and service quality across provinces (David, 2003). In Davao Oriental, disparities in extension service performance among municipalities are evident due to varying capacities and resource allocations. These gaps present both a challenge and an opportunity: the province must harmonize local extension governance with national digital agriculture strategies to ensure equitable service delivery. The implication to the article is that institutional coordination across provincial and municipal levels is essential for digital extension to take root and scale.

One of the most persistent challenges is the lack of a clear provincial digital extension roadmap that aligns local priorities with the Department of Agriculture's national frameworks, such as the Digital Agriculture Strategy and Smart Agriculture Program. Many LGUs in Davao Oriental operate without digital integration plans or dedicated budgets for ICT tools and infrastructure (NEDA XI, 2022). This absence of policy clarity

leads to fragmented efforts and a reactive, rather than proactive, approach to technology diffusion. Therefore, this article must argue for the development of localized policies that define digital extension goals, roles of stakeholders, and resource mobilization mechanisms to create an enabling environment for smart farming.

Capacity-building is another pressing issue. Literature consistently shows that the effectiveness of digital extension depends largely on the competency and readiness of extension workers (Rivera & Sulaiman, 2009; Lamban et al., 2017). In Davao Oriental, many extension personnel lack access to formal training in ICT tools, data analytics, and digital facilitation techniques. This limits their confidence and capability to support farmers in navigating digital tools such as mobile apps, geotagging systems, or digital recordkeeping. To resolve this, institutional investments are needed in regular upskilling programs, possibly led by SUCs like Davao Oriental State University in partnership with the Agricultural Training Institute (ATI). This highlights the article's position that building human capital must accompany the introduction of digital innovations.

Equally important is the development of robust digital infrastructure, including internet connectivity, electricity, and access to digital devices, particularly in upland and remote communities. Studies have shown that digital divide issues—especially in geographically isolated and disadvantaged areas—limit the effectiveness of even the best-designed digital extension tools (Fabregas et al., 2019). In Davao Oriental, where several barangays remain underserved by ICT infrastructure, government and private sector investment in digital access must be prioritized as a foundational policy component. This supports the article's argument that physical infrastructure is a precondition for digital transformation and that extension services must advocate for its inclusion in rural development plans.

Farmer support mechanisms—such as digital literacy campaigns, financial assistance for tech adoption, and access to farmer cooperatives—are also essential to ensuring inclusive digitalization. Literature suggests that without targeted support, digital agriculture may reinforce existing inequalities, benefiting only a small portion of tech-savvy or well-connected farmers (Klerkx et al., 2019). In Davao Oriental, extension services must design inclusive models that account for diverse learning needs, economic capacities, and gender perspectives. The article, therefore, must frame extension policy reform not only as a technological imperative but also as a social equity issue.

Strengthening digital extension in Davao Oriental requires a multifaceted policy and institutional approach. This includes aligning local policies with national strategies, investing in the digital capacity of extension workers, upgrading rural infrastructure, and embedding equity into farmer support systems. The literature affirms that digital extension cannot succeed without addressing these foundational elements. Thus, this review article contributes to policy discourse by presenting a contextualized and evidence-based roadmap for transforming agricultural extension into a digitally empowered and inclusive system in the province.

Summary Table

Theme	Key Findings	Local Case Data (Davao Oriental)	Implications for Extension Services
Extension System Readiness	Capacity gaps in digital knowledge, infrastructure limitations	LGUs lack ICT tools; extension agents have limited training (Lamban et al., 2017)	Upskilling needed; digital infrastructure development is critical
Digital Tools and Adoption Barriers	Mobile tools and smart tech available, but adoption is slow	Mobile pest alerts and SMS advisories piloted	Extension agents must lead hands-on tech demonstrations and training
Role of SUCs and Innovation Hubs	SUCs are key actors in research but weak in long-term scaling	Developed irrigation automation, mobile pest advisory	Institutionalize tech transfer and university–LGU partnerships
Farmer Cooperatives and Peer Learning	Cooperatives aid diffusion but face digital and governance capacity challenges	Coconut farmer groups tested mobile weather updates but lacked sustained use	Cooperatives need capacity-building support for ICT integration

NGO and Private Sector Participation	NGOs and telcos pilot tools but projects are often short-term	CRS and AsiaDHRRA introduced community-based ICT programs (AsiaDHRRA, 2021)	Collaborate with NGOs to embed tools in LGU and SUC extension systems
Policy and Institutional Alignment	National strategies exist, but local execution is fragmented	DA XI projects ongoing; weak alignment with municipal plans (NEDA XI, 2022)	Align provincial extension planning with PDAS and Smart Agri policies

Synthesis

This review is limited by the availability of localized empirical studies specific to Davao Oriental. Many findings were drawn from national reports and generalized studies, which may not capture the province's full institutional and socio-cultural nuances. Additionally, while thematic coding and synthesis were applied, the absence of a formal quality assessment of reviewed sources may limit the robustness of comparative conclusions.

The body of literature reviewed reveals a growing convergence between global smart agriculture trends and localized agricultural development strategies in the Philippines, particularly in rural provinces such as Davao Oriental. Digital and smart farming technologies—such as precision irrigation, IoT-based pest management, mobile-based advisories, and digital marketplaces—are increasingly seen as critical tools in addressing the productivity, climate, and sustainability challenges faced by the agriculture sector (Wolfert et al., 2017; DA & IRRI, 2021). However, their successful integration into local farming systems remains uneven due to structural, institutional, and socio-cultural barriers. This synthesis underscores the central thesis of the article: that agricultural extension services are pivotal in localizing, adapting, and scaling digital innovation in agriculture.

Agricultural extension in Davao Oriental has historically operated within a decentralized and resource-constrained governance framework, making it both flexible and fragmented (David, 2003). The existing modalities—such as farmer field schools, learning sites, and demonstration farms—provide a strong foundation for participatory learning, but are yet to be fully digitalized. The literature consistently points to low digital literacy, inadequate infrastructure, and limited institutional support as persistent barriers to digital transformation. These limitations position extension agents not only as technology disseminators but also as digital capacity-builders, trust brokers, and innovation mediators (Rivera & Sulaiman, 2009; Lamban et al., 2017).

Promising innovations have emerged through localized research and development (R&D) projects, especially those led by Davao Oriental State University (DOrSU) and its partner agencies. Pilot initiatives involving automated irrigation, mobile pest advisory systems, and climate-smart technologies demonstrate the feasibility of smart farming models. Yet, the absence of strong technology transfer mechanisms, inter-agency coordination, and post-project sustainability strategies hampers their broader adoption (Palis et al., 2015; DOrSU, 2022). The literature emphasizes that institutionalizing these innovations within the extension system is necessary for long-term impact.

Moreover, the participation of farmer cooperatives, private agri-tech actors, and NGOs introduces new pathways for technology diffusion. Cooperatives provide platforms for collective learning and scaling of innovations, while private and NGO partners supply advanced technologies, infrastructure, and training systems (Basu et al., 2021; Klerkx et al., 2019). However, the literature also highlights issues of digital exclusion, sustainability, and ethical concerns such as data ownership. Extension services must serve as critical linkages between these actors and smallholder farmers, ensuring that technologies are inclusive, affordable, and relevant to the socio-economic conditions of Davao Oriental's diverse farming communities.

Policy support exists at the national level through initiatives like the Philippine Digital Agriculture Strategy (PDAS), F2C2, and Smart Agriculture Program. Nonetheless, the translation of these frameworks into provincial and municipal contexts remains limited by capacity and governance gaps (DA, 2020; NEDA XI, 2022). Extension workers are often under-equipped to implement these programs, and infrastructure challenges

persist. The literature recommends localized policy alignment, structured capacity-building programs, and stronger feedback mechanisms to ensure that digital extension becomes both scalable and sustainable.

The synthesis of the literature reveals that digital and smart farming technologies hold transformative potential for agriculture in Davao Oriental. However, this potential can only be realized through a reimagined extension system that is digitally capable, farmer-centered, and institutionally supported. The article's core contribution lies in presenting a framework that recognizes extension services as not just passive conduits of technology, but as active agents of change—co-creating, contextualizing, and championing innovations that can shape the future of farming in the province.

This review synthesized diverse literature to examine how agricultural extension systems facilitate or hinder the adoption of digital and smart farming technologies in Davao Oriental. It found that while national frameworks such as the Philippine Digital Agriculture Strategy (PDAS) and Farm and Fisheries Clustering and Consolidation (F2C2) offer direction, implementation at the provincial level is fragmented and constrained by resource limitations, low digital capacity, and weak inter-agency coordination (DA & IRRI, 2021; NEDA XI, 2022).

Key strengths in the local innovation ecosystem include active involvement by SUCs like DOrSU in piloting digital tools, the presence of organized farmer cooperatives, and the entry of private and NGO-led ICT initiatives. However, the integration of these innovations into the mainstream extension system remains shallow. Most pilot projects lack sustainability mechanisms, while capacity-building programs for extension workers are ad hoc and underfunded (DOrSU, 2022; Lamban et al., 2017). Furthermore, the digital divide persists, particularly among older and remote farmers, underscoring the need for inclusive digital literacy and support systems.

Several critical gaps emerged:

1. Lack of longitudinal studies tracking the long-term impact of digital extension interventions.
2. Limited evaluations of SUC–LGU partnerships in sustaining digital agriculture initiatives.
3. Minimal focus on gender and generational disparities in digital adoption at the farmer level.
4. Absence of impact metrics to assess the effectiveness of cooperative- and NGO-led technology diffusion models.

KEY FINDINGS

A key finding from the literature is that while digital and smart farming technologies—such as mobile advisory platforms, automated irrigation, and precision agriculture tools—are becoming more available through national initiatives, their actual adoption in Davao Oriental remains limited due to digital illiteracy, infrastructure gaps, and localized governance issues (David, 2003; Fabregas et al., 2019). The review highlights that the decentralized agricultural extension system in the Philippines, while providing flexibility, has resulted in inconsistent delivery of digital extension services across municipalities. This underscores the urgent need for coordinated, province-wide digital extension strategies that align with national policies such as the Philippine Digital Agriculture Strategy (DA & IRRI, 2021).

Another significant insight is the untapped potential of SUCs like Davao Oriental State University (DOrSU), farmer cooperatives, and public-private-NGO partnerships in scaling digital innovations. DOrSU has pioneered R&D programs on ICT-based solutions, while cooperatives and NGOs have enabled community-based access to mobile tools and digital advisory systems (DOrSU, 2022; AsiaDHRRA, 2021). However, the lack of sustainability mechanisms and institutional embedding has limited the long-term impact of these initiatives. These findings reinforce the role of agricultural extension not just as a technology conduit, but as a collaborative hub for localizing innovation and ensuring that digital tools reach smallholder farmers equitably (Klerkx et al., 2019).

The literature emphasizes that policy reform and institutional support are crucial to enabling effective digital extension. The review identifies gaps in the capacity of extension workers, limited digital infrastructure in

remote communities, and a need for inclusive farmer support systems such as financial access and digital literacy training (Lamban et al., 2017; Rivera & Sulaiman, 2009). Without targeted investments in human capital, infrastructure, and participatory policy-making, digital agriculture may further marginalize already underserved farmers. Therefore, a reimagined extension system must be digitally empowered, inclusive, and responsive to the socio-economic realities of Davao Oriental.

CONCLUSION

The literature clearly affirms that digital and smart farming technologies have the potential to transform agricultural productivity, resilience, and sustainability in rural areas such as Davao Oriental. However, their successful integration depends heavily on the capacity and responsiveness of the agricultural extension system. While national programs like the Philippine Digital Agriculture Strategy and the Smart Agriculture Program provide policy direction, localized implementation remains inconsistent due to fragmented governance, weak infrastructure, and limited digital literacy among both farmers and extension workers (David, 2003; DA & IRRI, 2021). As such, the transformation toward digital agriculture cannot proceed without reconfiguring local extension systems to become more adaptive, inclusive, and technology-driven.

The review highlights that advancing digital and smart farming technologies in Davao Oriental will require more than just the availability of digital tools—it will demand an ecosystem-wide approach where extension workers are empowered, policies are localized, infrastructures are strengthened, and farmers are at the center of innovation. Agricultural extension should no longer be viewed as a peripheral service but as a catalyst for inclusive digital transformation in agriculture. Moving forward, strategic investment in human capital, institutional coordination, and knowledge-sharing platforms will be critical to realizing a digitally inclusive future for farming in the province (Rivera & Sulaiman, 2009; Fabregas et al., 2019).

This underscores the critical role of agricultural extension in enabling the adoption of digital and smart farming technologies in Davao Oriental. While national strategies like PDAS provide policy direction, local implementation is hindered by weak infrastructure, limited digital literacy, and fragmented coordination. SUCs, NGOs, and farmer cooperatives present valuable channels for innovation diffusion, but efforts remain underutilized without institutional support and policy alignment.

To move forward, extension services must be reimagined not merely as information carriers but as digitally empowered systems that connect stakeholders, localize innovations, and promote inclusive rural development. Bridging the gaps in digital capacity, governance, and stakeholder collaboration is essential to transforming Davao Oriental's agriculture into a future-ready, resilient system.

RECOMMENDATION

To strengthen digital extension in Davao Oriental, the following actions are proposed:

1. Develop a Localized Digital Extension Roadmap

-Align LGU programs with PDAS and Smart Agriculture policies.

-Include digital inclusion targets and farmer-cooperative integration.

2. Invest in Capacity-Building for Extension Workers

-Conduct modular ICT training in partnership with SUCs (e.g., DOrSU).

-Include digital literacy, facilitation, and data interpretation skills.

3. Strengthen Multi-Stakeholder Collaboration

-Formalize partnerships among LGUs, SUCs, NGOs, and agri-tech startups.

-Create innovation hubs and co-managed demonstration sites.

4. Upgrade Rural Digital Infrastructure

-Expand internet access and ICT device support in remote barangays.

-Advocate for inclusion in national broadband rollout programs.

5. Embed Inclusion and Equity Mechanisms

-Design digital tools for women, older farmers, and indigenous groups.

-Support cooperatives as peer-led digital literacy platforms.

To strengthen digital and smart farming implementation in Davao Oriental, it is recommended that the provincial government, in coordination with the Department of Agriculture (DA), adopt a localized digital extension policy framework aligned with the Philippine Digital Agriculture Strategy (PDAS) and Farm and Fisheries Clustering and Consolidation (F2C2) program. This framework should institutionalize digital capacity-building for extension workers, integrate ICT-based advisory systems into local agricultural plans, and allocate dedicated funding for digital infrastructure development in remote areas (DA & IRRI, 2021; NEDA XI, 2022). Embedding digital literacy and smart technology use within farmer training curricula will also ensure that digital transformation is inclusive, farmer-centered, and sustainable.

Furthermore, policies should promote stronger collaboration among SUCs, LGUs, private sector innovators, and NGOs to create a province-wide agri-digital innovation ecosystem. Programs should support the co-development and scaling of locally tested technologies—such as mobile pest monitoring, automated irrigation, and weather advisory apps—through partnerships led by institutions like Davao Oriental State University (DOrSU) (DOrSU, 2022; Rivera & Sulaiman, 2009). It is also essential to strengthen farmer cooperatives as digital learning hubs, supported by extension agents trained in participatory facilitation and ICT. With these programmatic and policy interventions, digital extension in Davao Oriental can move beyond experimentation toward sustainable and inclusive transformation.
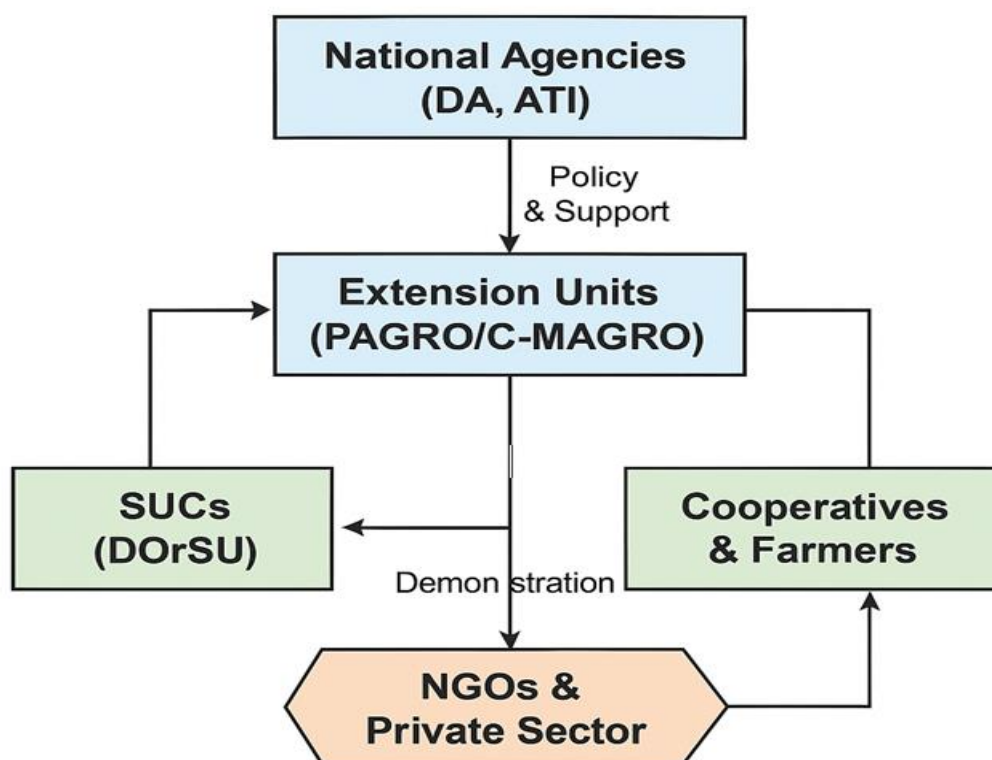
Recommended Digital Extension Ecosystem

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