

Smart Agricultural Innovations for Resource-Efficient and Sustainable Farming

N. Narasimha Raju^{1*} , D. Abhishek² , K. Jaswanth Kumar³ , P. Bhanu Prasad⁴  and B. Hima Chandra⁵ 

^{1,2,3,4,5}B. Tech (Computer Science), Centurion University of Technology & Management, Vizianagaram, Andhra Pradesh, India

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*Corresponding Author

N. Narasimha Raju

E-mail: simha6101@gmail.com

Co-Author(s):

Author 2: D. Abhishek

E-mail: duragasiabhishek@gmail.com

Author 3: K. Jaswanth Kumar

E-mail: kjaswanthkumar7@gmail.com

Author 4: P. Bhanu Prasad

E-mail: jnaneshpathivada7@gmail.com

Author 5: B. Hima Chandra

E-mail: himachandra6501@gmail.com

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ABSTRACT

Purpose: Resource constraints in water, energy, and land, combined with rising food demand, are pushing agricultural systems worldwide toward technology-enabled, resource-efficient practices. While much existing literature examines these smart agricultural innovations from an engineering standpoint, their adoption, scaling, and impact are ultimately shaped by economic, entrepreneurial, and social forces. This review synthesises literature on smart agricultural innovations through a social-science lens, focusing on adoption behaviour, agripreneurship, financial inclusion, gender and rural equity, and policy design. Design/Methodology/Approach: A narrative literature review was conducted, drawing on peer-reviewed journal articles, systematic reviews, and reports from international development agencies published between 2019 and 2026, identified through targeted searches of academic databases and institutional repositories using keywords related to smart farming, precision agriculture, agripreneurship, digital agriculture, and rural financial inclusion. Findings: Four cross-cutting themes emerged: (1) technology adoption is governed less by technical performance than by cost, trust, and contextual fit; (2) agripreneurship and youth-led rural enterprise depend on bundled access to finance, training, and market linkages rather than technology alone; (3) gender and the rural digital divide remain structural barriers to equitable adoption; and (4) government-led digital public infrastructure is emerging as a decisive enabler of inclusive scaling. Practical/Social Implications: The findings suggest that policy and investment should prioritise ecosystem-level enablers, financing, digital literacy, and inclusive design, over standalone technology deployment. Originality: The review contributes an integrated, socially grounded framework for understanding smart agricultural innovation as a rural development and entrepreneurship issue rather than a purely technical one.

Keywords: Agripreneurship; Digital Agriculture; Financial Inclusion; Precision Agriculture; Resource Efficiency; Sustainable Farming

1. Introduction

Agriculture sits at the intersection of two mounting pressures: the need to produce substantially more food for a growing global population, and the need to do so while consuming markedly less water, land, and energy. Farmland expansion has slowed even as the number of

farms feeding the world has grown more concentrated among fewer, larger operations in some regions, while remaining fragmented among hundreds of millions of smallholders elsewhere (Lowder et al., 2021). This structural diversity means that no single technological fix can deliver resource efficiency uniformly across

global agriculture. Instead, the past decade has seen the emergence of a broad family of smart agricultural innovations, precision sensing, satellite and drone-based monitoring, artificial intelligence (AI)-enabled decision support, automated irrigation, and digital farm management platforms, that promise to reconcile productivity with sustainability by matching resource use precisely to crop and field-level need.

Much of the existing scholarship on these innovations approaches them from an engineering or agronomic perspective, evaluating sensor accuracy, irrigation efficiency, or yield gains under controlled conditions. This technical literature is valuable, but it is not sufficient to explain why smart agricultural technologies that perform well in trials frequently fail to scale in practice. A recurring finding across recent reviews is that adoption, or its absence, is driven overwhelmingly by economic, institutional, and social factors: the cost of technology relative to smallholder income, the availability and terms of credit, the trust farmers place in unfamiliar recommendations, the digital literacy and connectivity available in rural areas, and the presence or absence of policy support (Bashiru et al., 2024; Finizola e Silva et al., 2024; John et al., 2023). In other words, smart agriculture is as much a social and economic phenomenon as it is a technical one, and understanding it requires a lens grounded in the humanities and social sciences rather than in engineering alone.

This concern is particularly salient given that the large majority of the world's farms are smallholdings of two hectares or less, operated by households for whom agriculture is inseparable from livelihood, entrepreneurship, and intergenerational opportunity (Lowder et al., 2021). For these households, the decision to adopt a sensor, a mobile advisory service, or a drone-spraying subscription is not merely a technology choice; it is an entrepreneurial and financial decision made under conditions of limited capital, uncertain returns, and, in many regions, unequal access to land, credit, and information along gender lines (FAO, 2023). Understanding smart agricultural innovation therefore requires attention to agripreneurship, the emergence of technology-enabled rural enterprise, to financial inclusion, and to the structural barriers, including the gendered digital divide, that shape who can participate in this transition and who is left behind.

This review addresses that gap by synthesising literature on smart agricultural innovations through an explicitly social-science lens. Rather than cataloguing the technical specifications of individual tools, it asks: what economic, entrepreneurial, and institutional conditions determine whether resource-efficient farming technologies are adopted, sustained, and scaled

equitably? In pursuing this question, the review draws together four bodies of literature that are often treated separately: technology adoption studies in agricultural economics, agripreneurship and rural enterprise research, financial inclusion and rural credit scholarship, and gender and digital-divide literature, before considering how government-led digital public infrastructure is beginning to reshape the landscape in which all of these dynamics play out, using India's ongoing digital agriculture reforms as an illustrative case. The remainder of the paper proceeds as follows: the next section situates the review within existing conceptual and theoretical work; this is followed by the review methodology; the results section presents a thematic synthesis of the literature; the discussion interprets these themes in relation to one another; and the paper closes with conclusions, implications, and limitations.

2. Literature Review and Conceptual Framework

2.1 *Technology Adoption in Smallholder and Commercial Agriculture*

A substantial body of research has examined why farmers adopt, or fail to adopt, precision and smart farming technologies. Reviewing systematic literature on precision agriculture adoption among small-scale farmers, John et al. (2023) identified cost, farm size, access to technical support, and supporting policy as the dominant factors governing uptake, concluding that technologies delivering clearly demonstrable and near-term economic benefit are far more likely to be adopted than those whose payoff is diffuse or delayed. This finding is echoed in qualitative work among small-scale commercial family farms in China, where Kendall et al. (2022) found that adoption decisions were shaped less by the technical sophistication of a tool than by farmers' trust in the information it produced and its compatibility with existing routines and social networks.

At the sub-Saharan African level, Bashiru et al. (2024) conducted a systematic review following PRISMA procedures across 48 eligible studies and found that most smart farming technologies being actively promoted to smallholders remain conventional climate-smart agricultural practices, such as land and water management and improved varieties, rather than the more advanced fourth-industrial-revolution innovations, including automation, the Internet of Things, and artificial intelligence, that dominate discussions of smart agriculture in higher-income contexts. Farmers' own responses to promoted technologies were found to be shaped heavily by socioeconomic circumstance and by the extent to which new tools could be layered onto existing indigenous knowledge rather than replacing

it outright. In a related systematic review focused specifically on climate-smart agriculture, Finizola e Silva et al. (2024) categorised the drivers and barriers to adoption across personal, farm-related, financial, environmental, and informational dimensions, concluding that access to credit in particular has a consistently positive and significant association with adoption across multiple African contexts, since credit access expands farmers' capacity to absorb the transaction, equipment, and input costs associated with new practices.

A parallel line of research has examined digital agriculture ecosystems more broadly, that is, not individual devices but the surrounding platforms, connectivity, and business models required to make digital tools usable by smallholders. Gumbi et al. (2023), in a systematic review of digital agriculture for smallholder farmers, found that the dominant barriers reported in the literature concern digital infrastructure, affordability, and digital literacy or skills, and that research specifically addressing business-model innovation, that is, how digital agriculture services can be priced and delivered sustainably to low-income users, remains comparatively underdeveloped. This is a significant gap, since it suggests that even where digital tools exist, the absence of viable, farmer-appropriate delivery models constitutes an independent barrier distinct from the cost of the technology itself.

2.2 Agripreneurship and Rural Enterprise

A second relevant literature concerns agripreneurship, broadly defined as entrepreneurial activity that applies innovation, including but not limited to digital technology, to agricultural production, processing, or service delivery. This literature intersects with, but is analytically distinct from, the technology-adoption literature discussed above, because it treats the farmer or rural youth not simply as a technology user but as a potential enterprise founder or operator. Within this framing, technology adoption becomes one input among several, alongside access to finance, market linkages, and business skills, that determines whether a rural enterprise succeeds. Reviews of youth-led agribusiness in developing-country contexts consistently emphasise that technical training alone is insufficient without complementary access to financial services, expanded market opportunities, and supportive policy frameworks that address cross-cutting constraints such as gender inequality and social exclusion, a conclusion reflected in continental strategies such as the African Union's youth agribusiness policy architecture spanning 2017 to 2026.

This body of work suggests that smart agricultural technologies are best understood, from an entrepreneurship perspective, as enabling infrastructure for rural enterprise rather than as an end in themselves.

A drone survey service, a sensor-based advisory subscription, or a digital marketplace platform each represents both a productivity tool for existing farmers and a potential micro-enterprise opportunity for rural youth who can be trained to operate, maintain, or resell access to these technologies within their communities. This dual framing, technology as productivity tool and technology as entrepreneurial opportunity, has important implications for how policy and investment should be designed, a point returned to in the discussion.

2.3 Financial Inclusion, Credit Access, and Rural Investment

Access to finance is repeatedly identified across the reviewed literature as a precondition for, rather than a consequence of, smart agricultural technology adoption. Evidence reviewed by the Food and Agriculture Organization's Investment Centre indicates that access to credit, and particularly microloans, enables farmers to invest in new technology and inputs, access new markets, and increase productivity, but that adoption of financial products in turn depends on liquidity, awareness, and social dynamics within farming communities (FAO Investment Centre, 2025). This creates a structural challenge: the farmers who stand to benefit most from resource-efficient technologies, those operating on the thinnest margins, are often the least able to access the credit needed to adopt them, a pattern that risks reproducing existing inequality between well-capitalised and resource-constrained farms even as smart agriculture technologies proliferate.

Financial exclusion in agriculture has historically been reinforced by conventional lending models that require collateral such as titled land, a requirement that disproportionately excludes women, tenant farmers, and youth who frequently lack such assets even where they perform the majority of agricultural labour (FAO, 2023). In response, alternative and technology-enabled financing models, including mobile-based credit scoring drawing on farm transaction and cash-flow data rather than land title, have begun to emerge as a mechanism for extending credit to previously excluded groups, though evidence on their long-run effectiveness remains mixed and context-dependent. The broader implication for this review is that resource-efficient farming technologies cannot be evaluated in isolation from the financial ecosystem that determines who can afford to adopt them.

2.4 Gender, the Rural Digital Divide, and Structural Exclusion

Gender inequality constitutes one of the most persistent and well-documented barriers to equitable

participation in agricultural innovation. Women perform a substantial share of agricultural labour worldwide, yet in many regions hold weaker land use and ownership rights than men, and continue to face unequal access to inputs, extension services, and finance (FAO, 2023). This structural disadvantage is compounded by a digital gender gap: women in low- and middle-income countries remain measurably less likely than men to own a smartphone or access mobile internet, which limits their ability to benefit from mobile-based advisory services, digital marketplaces, and mobile financial products that increasingly underpin smart agricultural ecosystems. Recent World Economic Forum analysis argues that closing this gap requires deliberately gender-intentional design of digital public infrastructure, including anonymised, gender-disaggregated data collection and interface design, such as multilingual translation platforms, that explicitly account for the access barriers women farmers face (World Economic Forum, 2025). Field initiatives such as the partnership between Maharashtra's state women's economic development corporation and international development actors to expand women farmers' access to digital agriculture illustrate both the scale of the opportunity, given that women constitute a majority of India's agricultural workforce, and the deliberate institutional effort required to realise it (World Economic Forum, 2023).

Taken together, this literature indicates that the digital and financial exclusion of women and youth in agriculture is not a side issue to be addressed after core technology deployment, but a structural feature of the adoption landscape that determines, from the outset, who is positioned to benefit from smart agricultural innovation and who is not.

2.5 Conceptual Framework

Drawing on the literature reviewed above, this paper adopts an ecosystem-based conceptual framework in which smart agricultural innovation is understood not as a discrete technology but as the interaction of four layers: a technology layer (sensing, AI, automation, and digital platforms); an economic layer (cost structures, credit access, and financing models); a social layer (gender, land tenure, digital literacy, and rural entrepreneurship); and an institutional layer (government policy, digital public infrastructure, and extension systems). Within this framework, resource-efficiency outcomes, reductions in water, fertiliser, energy, or labour use, are treated as emerging from the interaction of all four layers rather than from the technology layer alone. A technology that performs well on the technical layer but is unaffordable on the economic layer, incompatible with existing gender norms on the social layer, or unsupported by extension

services on the institutional layer is unlikely to achieve meaningful resource-efficiency outcomes at scale. This framework guides the thematic synthesis presented in the results section.

3. Methodology

This study adopts a narrative literature review design, appropriate for synthesising a conceptually diverse and rapidly evolving body of literature spanning agricultural economics, entrepreneurship, development studies, and information systems research, where a narrow systematic-review protocol restricted to a single discipline or outcome measure would exclude much of the relevant social-science literature. The review followed a structured, though not formally registered, search and selection process to maintain transparency and reduce selection bias.

3.1 Search Strategy and Sources

Literature was identified through targeted searches of academic search engines and publisher databases (including Google Scholar, MDPI, Springer, ScienceDirect, SAGE Journals, and Frontiers), supplemented by reports and policy documents from international development organisations, including the Food and Agriculture Organization of the United Nations, the World Bank, and the World Economic Forum, and by official government publications relevant to India's digital agriculture policy. Search terms combined core concepts using Boolean operators, including combinations of "smart farming," "precision agriculture," "climate-smart agriculture," "digital agriculture," "agriprenurship," "rural entrepreneurship," "agricultural credit," "financial inclusion," "gender digital divide," and "technology adoption," each paired with terms denoting smallholder or developing-country contexts. The search was restricted to English-language sources published between 2019 and 2026 to ensure relevance to the current state of digital and precision agriculture technology, while allowing inclusion of a small number of earlier foundational sources on farm structure and financial inclusion where directly relevant.

3.2 Screening and Selection Criteria

Sources were included if they (a) addressed smart, precision, climate-smart, or digital agricultural technologies; (b) engaged substantively with economic, entrepreneurial, financial, gender-related, or policy dimensions of adoption or impact, rather than purely technical or agronomic performance; and (c) were published in a peer-reviewed journal, or issued by a recognised international development, government, or research institution. Sources were excluded if they were

purely engineering-focused technical evaluations with no discussion of adoption, economic, or social dimensions, or if they could not be verified against a traceable original publication. Priority was given to systematic reviews and meta-analyses where available, as these aggregate findings across larger underlying evidence bases than individual primary studies.

3.3 Analytical Approach

Selected sources were read in full and coded thematically using the four-layer conceptual framework outlined in Section 1.5 as an initial coding structure, which was then refined inductively as recurring sub-themes, adoption drivers and barriers, agripreneurship and enterprise models, financial inclusion mechanisms, and gender and digital-divide dynamics, emerged across sources. This thematic synthesis approach is well suited to review questions concerned with explaining a phenomenon (why adoption succeeds or fails) rather than quantifying its magnitude, and is consistent with established narrative and thematic review practice in the social sciences. The results are organised around these themes in the following section.

4. Results

The thematic synthesis of the reviewed literature yielded four principal findings, presented below, each corresponding to one layer of the conceptual framework introduced in Section 1.5.

4.1 Adoption Is Governed by Economic Fit, Not Technical Performance

Across every adoption-focused study reviewed, technical performance emerged as a necessary but insufficient condition for adoption. John et al. (2023) found that farm size, cost, access to technical support, and policy support were the dominant determinants of precision agriculture adoption among small-scale farmers, a pattern corroborated by Kendall et al. (2022), who found that Chinese family farmers weighed a technology's compatibility with existing routines and social trust networks as heavily as its technical claims. Bashiru et al. (2024) similarly found that, despite the availability of advanced fourth-industrial-revolution technologies, sub-Saharan African smallholders overwhelmingly continue to adopt conventional, lower-cost climate-smart practices, indicating a persistent gap between the technologies being promoted by researchers and private firms and those farmers can realistically absorb given their economic circumstances. Gumbi et al. (2023) extended this finding to digital agriculture platforms specifically, concluding that affordability and the absence of viable business

models tailored to smallholder economics, rather than a lack of underlying digital solutions, constitute the primary constraint on digital agriculture uptake.

4.2 Agripreneurship Depends on Bundled, Not Standalone, Support

The reviewed agripreneurship literature converges on the finding that youth-led and technology-enabled rural enterprise succeeds only where technical exposure is bundled with financing, market access, and mentorship, rather than delivered as a standalone technology intervention. Continental and national youth agribusiness strategies reviewed in this literature explicitly combine access to financial services with expanded market opportunities, climate-smart technology promotion, and attention to gender and social exclusion as interdependent pillars, rather than treating technology adoption as a sufficient intervention on its own. This suggests that smart agricultural technologies function most effectively as entrepreneurial infrastructure when embedded within a wider enterprise-support ecosystem, a finding directly relevant to policy design, discussed further below.

4.3 Financial Exclusion Constrains Adoption Among Those Who Would Benefit Most

Findings across the financial inclusion literature indicate a structural mismatch between need and access: farmers operating on the thinnest margins, who stand to gain the most from resource-efficient technology, are frequently the least able to access the credit required to adopt it. The FAO Investment Centre (2025) review found that credit access, particularly through microloans, enables investment in technology, inputs, and market access, but that uptake of financial products depends on liquidity and social dynamics that are themselves shaped by existing inequality. Collateral-based lending models, which require assets such as titled land that women and tenant farmers frequently lack, compound this exclusion (FAO, 2023). The literature reviewed suggests that alternative, technology-enabled credit-scoring approaches represent a promising but still-maturing response to this constraint, rather than a fully resolved solution.

4.4 Gender and Digital Exclusion Remain Structural, Not Incidental, Barriers

The gender and digital-divide literature reviewed indicates that women's lower access to land rights, extension services, and mobile technology is not an isolated or incidental barrier but a structural feature of the agricultural innovation landscape that shapes adoption outcomes across every other theme identified

in this review (FAO, 2023). Because women constitute a majority of the agricultural workforce in a number of major farming economies, their exclusion from digital and financial innovation represents not a marginal equity concern but a first-order constraint on the aggregate resource-efficiency gains that smart agriculture can realistically deliver at national scale. The World Economic Forum (2025) argues that closing this gap requires deliberately gender-intentional design of digital public infrastructure from the outset, rather than retrofitting inclusion into systems designed without it, a conclusion supported by field-level initiatives explicitly targeting women farmers' access to digital agriculture platforms in states such as Maharashtra, India (World Economic Forum, 2023).

4.5 Digital Public Infrastructure Is Emerging as a Decisive Institutional Enabler

A final and increasingly significant theme concerns the role of government-led digital public infrastructure in shaping the conditions under which the preceding three dynamics play out. India's Digital Agriculture Mission, approved with a central government outlay in the range of several thousand crore rupees, illustrates this institutional layer in practice. Its core components include AgriStack, a shared digital identity and land-record system for farmers modelled on the country's existing digital identity infrastructure, a nationwide Digital Crop Survey combining satellite imagery and artificial intelligence for crop area estimation, and a Krishi decision-support system providing AI-based advisory services in multiple regional languages (Press Information Bureau, Government of India, 2024). By linking farmer identity, land records, and crop data into a single interoperable system, this infrastructure is designed to streamline farmers' access to credit, insurance, and subsidy schemes that have historically been constrained by fragmented documentation and verification processes, directly addressing the financial-exclusion barrier identified in Theme 3.3. At the same time, commentary on the initiative cautions that reliance on formal land-ownership records risks excluding tenant farmers and sharecroppers who lack registered tenancy documentation, illustrating that digital public infrastructure, if not deliberately designed for inclusion, can reproduce rather than resolve existing structural exclusion. This tension between infrastructure as an enabler of inclusion and infrastructure as a potential new gatekeeper recurs across the broader digital agriculture literature and is addressed further in the discussion.

5. Discussion

The results presented above point to a consistent underlying pattern: the technical capability of smart

agricultural innovations has, in most of the contexts reviewed, outpaced the economic, entrepreneurial, and institutional infrastructure required to translate that capability into equitable, scaled resource-efficiency outcomes. This pattern echoes the broader argument that transformative change in agri-food systems is achieved not through isolated technological breakthroughs but through the deliberate bundling of innovations, financing, and institutional support into coherent packages suited to local conditions (Barrett et al., 2022). The findings of this review extend that argument specifically to the social dimensions of smart agriculture: bundling, in the cases reviewed, must include not only complementary technologies but also credit products, entrepreneurship training, and gender-intentional design if resource-efficiency gains are to reach the smallholders, women, and rural youth who make up the majority of the world's farming population.

This has a direct implication for how the relationship between agripreneurship and technology adoption should be understood. Rather than treating rural youth and women primarily as technology adopters whose behaviour is to be encouraged or nudged, the agripreneurship literature reviewed here suggests they are more productively understood as potential technology intermediaries and enterprise operators, individuals who can be supported to build small businesses around drone spraying services, sensor installation and maintenance, or digital advisory subscriptions within their own communities. This reframing shifts the appropriate unit of policy intervention from the individual farm household to the local rural enterprise ecosystem, a shift broadly consistent with the finding that youth agribusiness strategies succeed only when technology promotion is combined with financial and market-access support rather than delivered in isolation.

The financial inclusion findings similarly suggest that policy and investment aimed at expanding smart agriculture adoption should prioritise de-risking credit for smallholders, women, and youth ahead of, or at minimum alongside, direct technology subsidies. Where credit remains collateral-based and inaccessible to those without titled land, even a fully subsidised technology may fail to reach its intended users because complementary inputs, maintenance, or working capital remain unaffordable. The cautious optimism found in the literature regarding alternative, transaction-based credit scoring reflects a genuine but still-unproven pathway around this constraint, one that merits continued monitoring rather than uncritical promotion.

The case of India's Digital Agriculture Mission illustrates both the promise and the risk inherent in the institutional layer of the conceptual framework. On one

hand, a unified, interoperable digital identity and land-record system has clear potential to resolve long-standing frictions in credit, insurance, and subsidy delivery that have historically disadvantaged smallholders, a direct institutional response to the financial-exclusion theme identified above. On the other hand, the same infrastructure, if built around formal land title as its foundational credential, risks systematically excluding the tenant farmers, sharecroppers, and, disproportionately, women who lack such documentation, precisely the groups identified throughout this review as facing the most acute barriers to begin with. This suggests that digital public infrastructure for agriculture is not inherently inclusive or exclusionary; its distributional effects depend entirely on design choices made at the outset, reinforcing the World Economic Forum's (2025) argument that gender- and equity-intentional design must be built into digital agricultural infrastructure from its foundation rather than added retrospectively.

Taken as a whole, these findings support a reframing of "smart agriculture" away from a primarily technological category and toward a primarily institutional and entrepreneurial one. The central research and policy question this review surfaces is not which sensor, algorithm, or platform performs best under trial conditions, but which combination of financing, training, and infrastructure design allows a given technology to reach, and be sustainably used by, the farmers, entrepreneurs, and communities for whom it is intended.

6. Conclusion

This review set out to examine smart agricultural innovations for resource-efficient and sustainable farming through a social-science lens, focused on adoption behaviour, agripreneurship, financial inclusion, and gender and institutional equity, rather than through a purely technical or agronomic framing. The synthesis of literature across these domains indicates that the primary constraints on the scaled, equitable adoption of resource-efficient farming technologies are economic and institutional rather than technical: cost relative to smallholder income, access to credit, digital and gender-based exclusion, and the design of surrounding policy and infrastructure. Agripreneurship emerged as a particularly important but underutilised framing, one that repositions rural youth and women not merely as technology users to be persuaded but as potential enterprise operators around whom local, technology-enabled rural economies can be built. The case of India's Digital Agriculture Mission demonstrates that government-led digital public infrastructure is becoming a decisive variable in this landscape, capable of either resolving or reinforcing

existing patterns of exclusion depending on how deliberately inclusion is designed into its foundations. Overall, the review supports the conclusion that achieving resource-efficient, sustainable farming at scale requires treating smart agricultural technology as one component of a broader socio-economic ecosystem, rather than as a self-sufficient solution.

6.1 Implications of the Study

The findings of this review carry several implications for policymakers, development practitioners, financial institutions, and researchers concerned with agricultural innovation. For policymakers, the results suggest that public investment in smart agriculture should be evaluated not solely on the technical merits of the technologies being promoted but on the extent to which complementary financing, extension, and infrastructure are in place to enable their use by the smallholders, women, and youth who make up the majority of the farming population. A subsidy or distribution programme for sensors, drones, or digital advisory platforms is unlikely to achieve its intended resource-efficiency outcomes if it is not accompanied by parallel investment in affordable credit and digital literacy training, since the review indicates that these factors, rather than the technology itself, most frequently determine whether adoption occurs and is sustained. This implies a need for closer coordination between ministries or departments responsible for agriculture, rural finance, and digital infrastructure, which in many contexts continue to operate as separate policy silos despite the interdependence documented throughout this review.

For development practitioners and non-governmental organisations working in rural entrepreneurship, the review's agripreneurship findings suggest that technology-focused interventions are likely to have greater and more durable impact when designed explicitly as enterprise-support programmes, combining technical training with access to start-up finance, mentorship, and market linkages, rather than as one-off technology distribution or awareness campaigns. This is particularly relevant for programmes targeting rural youth, for whom the entrepreneurial framing offers a pathway to income generation that a purely productivity-oriented framing does not. For financial institutions, the review highlights a significant and only partially served market opportunity in designing credit products that do not depend on collateral inaccessible to women, tenant farmers, and youth, an area in which technology-enabled, transaction-based credit scoring shows promise but requires further institutional investment and regulatory support to mature into a reliable alternative to conventional lending. Finally,

for researchers, the review points to the continued need for interdisciplinary work that bridges agricultural engineering, economics, and gender studies, since the evidence reviewed here suggests that the technical and social dimensions of smart agriculture are empirically inseparable in determining real-world outcomes, even though they are frequently studied in isolation from one another within disciplinary silos. Institutions engaged in applied data-science and social-impact training are well positioned to contribute to this interdisciplinary research agenda, including through the kind of student-led review work presented here.

6.2 Limitations and Recommendations for Future Research

This review is subject to several limitations that should be considered when interpreting its findings. First, as a narrative rather than a formally registered systematic review, the source selection process, while structured and transparent, was not exhaustive and may not capture the full universe of relevant literature, particularly non-English-language sources and unpublished grey literature from national agricultural research systems, which may under-represent country-specific dynamics not covered in the international peer-reviewed literature consulted here. Second, the review synthesises evidence drawn primarily from sub-Saharan Africa, South and Southeast Asia, and India, reflecting the concentration of the underlying adoption and financial-inclusion literature in these regions; findings may not generalise fully to smallholder contexts in Latin America or to commercial farming contexts in high-income economies, which follow substantially different adoption pathways not explored in depth here. Third, because India's Digital Agriculture Mission is a recently launched and still-evolving initiative, the discussion of its institutional implications is necessarily based on programme design documents and early implementation reports rather than on long-term outcome evaluation, and its distributional effects, particularly for tenant farmers and women, should be treated as a hypothesis for future empirical testing rather than an established finding.

Future research would benefit from primary empirical studies that directly test the bundling hypothesis advanced in this review, for example, through comparative evaluation of technology-only interventions against technology-plus-financing-plus-training interventions among otherwise similar smallholder or youth agripreneur populations, to establish more rigorously whether bundled delivery produces materially better adoption and livelihood outcomes than standalone technology distribution. Longitudinal research tracking the gender-disaggregated outcomes of digital public infrastructure

programmes such as India's Digital Agriculture Mission, once sufficient implementation data become available, would also make a valuable contribution, allowing researchers to test empirically whether such infrastructure narrows or widens existing rural gender and tenancy-based inequalities as it scales. Finally, given the concentration of existing evidence in a relatively small number of countries, future comparative research across a wider range of agricultural and institutional contexts would strengthen the generalisability of the ecosystem-based conceptual framework proposed in this review.

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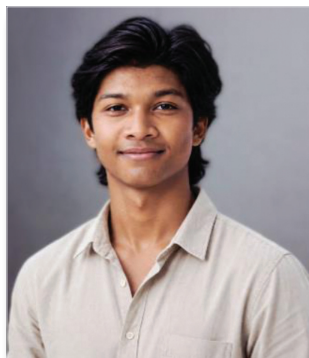
References

- Barrett, C. B., Benton, T. G., Cooper, K. A., Fan, S., Gandhi, R., Herrero, M., James, S., Kahn, M., Mason-D'Croz, D., Mathys, A., Nelson, A., Shen, J., Thornton, P., Bageant, E. R., Fanzo, J., & Wood, S. (2022). Bundling innovations to transform agri-food systems. *Nature Sustainability*, 5(12), 1074–1083. <https://doi.org/10.1038/s41893-022-00977-6>
- Bashiru, M., Ouedraogo, M., Ouedraogo, A., & Läderach, P. (2024). Smart farming technologies for sustainable agriculture: A review of the promotion and adoption strategies by smallholders in Sub-Saharan Africa. *Sustainability*, 16(11), Article 4817. <https://doi.org/10.3390/su16114817>
- FAO. (2023). The status of women in agrifood systems. Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/cc5343en>
- FAO Investment Centre. (2025). How farmers' access to finance boosts investment in agrifood systems. Food and Agriculture

- Organization of the United Nations. <https://www.fao.org/investment-centre/latest/news/detail/how-farmers--access-to-finance-boosts-investment-in-agrifood-systems/en>
- Finizola e Silva, M., Van Schoubroeck, S., Cools, J., & Van Passel, S. (2024). A systematic review identifying the drivers and barriers to the adoption of climate-smart agriculture by smallholder farmers in Africa. *Frontiers in Environmental Economics*, 3, Article 1356335. <https://doi.org/10.3389/frevc.2024.1356335>
- Gumbi, N., Gumbi, L., & Twinomurizi, H. (2023). Towards sustainable digital agriculture for smallholder farmers: A systematic literature review. *Sustainability*, 15(16), Article 12530. <https://doi.org/10.3390/su151612530>
- John, D., Hussin, N., Shahibi, M. S., Ahmad, M., Hashim, H., & Ametefe, D. S. (2023). A systematic review on the factors governing precision agriculture adoption among small-scale farmers. *Outlook on Agriculture*, 52(4), 469–485. <https://doi.org/10.1177/00307270231205640>
- Kendall, H., Clark, B., Li, W., Jin, S., Jones, G., Chen, J., Taylor, J., Li, Z., & Frewer, L. (2022). Precision agriculture technology adoption: A qualitative study of small-scale commercial “family farms” located in the North China Plain. *Precision Agriculture*, 23(1), 319–351. <https://doi.org/10.1007/s11119-021-09839-2>
- Lowder, S. K., Sánchez, M. V., & Bertini, R. (2021). Which farms feed the world and has farmland become more concentrated? *World Development*, 142, Article 105455. <https://doi.org/10.1016/j.worlddev.2021.105455>
- Press Information Bureau, Government of India. (2024). Digital Agriculture Mission: Tech for transforming farmers’ lives [Press release]. Ministry of Agriculture and Farmers Welfare. <https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=2051719>
- World Bank. (2024). What’s growing in digital agriculture: How digital technologies are transforming food systems. World Bank Group. <https://doi.org/10.1596/41092>
- World Bank, Bill & Melinda Gates Foundation, & Microsoft. (2025). Harnessing artificial intelligence for agricultural transformation in low- and middle-income countries. World Bank Publications.
- World Economic Forum. (2023, December). Leveraging tech for India’s women farmers in Maharashtra. <https://www.weforum.org/stories/2023/12/leveraging-technology-for-india-s-women-farmers-in-maharashtra/>
- World Economic Forum. (2025, September). How gender-intentional digital infrastructure can transform agriculture. <https://www.weforum.org/stories/2025/09/how-gender-intentional-digital-infrastructure-can-transform-agriculture/>

Biographical Statement of Author(s)

N. Narasimha Raju, is presently pursuing a B.Tech in Computer Science and Engineering with a specialisation in Data Science (2nd year) at Centurion University of Technology and Management, Vizianagaram, Andhra Pradesh. His academic interests include data science, artificial intelligence applications, and the use of digital technology to support rural entrepreneurship and resource-efficient agriculture. He has hands-on project experience across Android app development, AI/ML tooling, and academic coursework, and has participated in hackathons focused on applied software development.



Mr. N. Narasimha Raju

B. Tech Student
Centurion University of Technology & Management
Vizianagaram, Andhra Pradesh
India

E-mail: Simha6101@gmail.com

D. Abhishek, is presently pursuing a B.Tech in Computer Science and Engineering with a specialisation in Computer Networking at Centurion University of Technology and Management, Vizianagaram, Andhra Pradesh. He has participated in a 5G Small Cells hackathon and has a strong interest in building artificial intelligence projects and exploring emerging AI technologies.



Mr. D. Abhishek

B. Tech Student
Centurion University of Technology & Management
Vizianagaram, Andhra Pradesh
India

E-mail: duragasiabhishek@gmail.com

B. Hima Chandra, is presently pursuing a B.Tech in Computer Science and Engineering with a specialisation in Computer Networking at Centurion University of Technology and Management, Vizianagaram, Andhra Pradesh. He has participated in a 5G Small Cells hackathon and has a strong interest in building artificial intelligence projects and exploring emerging AI technologies.



Mr. B. Hima Chandra

B. Tech Student
Centurion University of Technology & Management
Vizianagaram, Andhra Pradesh
India
E-mail: himachandra6501@gmail.com

K. Jaswanth Kumar, is presently pursuing a B.Tech in Computer Science and Engineering with a specialisation in Computer Networking at Centurion University of Technology and Management, Vizianagaram, Andhra Pradesh. He has a keen interest in systems and computer networks.



Mr. K. Jaswanth Kumar

B. Tech Student
Centurion University of Technology & Management
Vizianagaram, Andhra Pradesh
India
E-mail: kjaswanthkumar7@gmail.com

P. Bhanu Prasad, is presently pursuing a B.Tech in Computer Science and Engineering with a specialisation in Computer Networking at Centurion University of Technology and Management, Vizianagaram, Andhra Pradesh. He has a keen interest in systems and computer networks.



Mr. P. Bhanu Prasad

B. Tech Student
Centurion University of Technology & Management
Vizianagaram, Andhra Pradesh
India
E-mail: jnaneshpathivada7@gmail.com