CLIMATE-SMART AGRICULTURE IN NIGERIA: A REVIEW OF PRECISION FARMING TECHNOLOGIES FOR FOOD SECURITY

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https://doi.org/10.35410/IJAEB.2026.1055

Received: 12 May 2026/Published: 20 June 2026

ABSTRACT

Nigeria faces acute challenges to agricultural productivity arising from intensifying climate variability, land degradation, and a rapidly growing population projected to exceed 400 million by 2050. Climate-smart agriculture (CSA), underpinned by precision farming technologies, offers a transformative pathway to sustaining food security while reducing greenhouse gas emissions and building resilience. This review synthesises current evidence on the adoption, performance, and barriers of precision farming tools, including remote sensing, unmanned aerial vehicles (UAVs), Internet of Things (IoT) sensors, variable rate technology (VRT), and artificial intelligence (AI), within the Nigerian agricultural context. A structured narrative review of peer-reviewed literature published between 2020 and 2025 was conducted, drawing on studies indexed in PubMed, Scopus, Web of Science, and AGRIS. Findings reveal that precision farming adoption in Nigeria remains low-to-nascent, constrained by high equipment costs, inadequate rural infrastructure, limited digital literacy, and policy implementation gaps. Nevertheless, emerging public–private partnerships, the National Agricultural Technology and Innovation Policy (NATIP) 2022–2027, and mobile digital advisory services present credible pathways for accelerated uptake. The review underscores that integrating precision technologies into existing smallholder farming systems, aligned with Nigeria's Nationally Determined Contributions, can simultaneously address food insecurity and climate change mitigation. Future research should prioritise context-specific, low-cost precision tools, farmer co-design approaches, and robust policy financing mechanisms to operationalise CSA at scale across Nigeria's diverse agroecological zones.

Keywords: Climate-smart agriculture; precision farming; food security; Nigeria; remote sensing; IoT; UAV; smallholder farmers.

1. INTRODUCTION

Agriculture remains the backbone of Nigeria's economy, contributing approximately 19–25% of gross domestic product and employing over 36% of the labour force. Nigeria is the most populous country in sub-Saharan Africa, and its capacity to feed a projected population of more than 400 million by 2050 hinges critically on the ability to transform traditional farming systems [1,2]. However, climate variability and change constitute existential threats to this ambition. Mean annual temperatures across Nigeria have risen by approximately 1.1°C since the pre-industrial baseline, with projections indicating increases of 1.5–3.0°C by 2050, depending on emissions trajectory [3]. Concomitantly, rainfall patterns have become increasingly erratic, with the Sahel and Sudan Savannah zones experiencing prolonged droughts while the humid south contends with intensified flooding and soil erosion [4].

Climate-smart agriculture (CSA) was formally conceptualised by the Food and Agriculture Organisation of the United Nations as an integrated approach that sustainably increases agricultural productivity, enhances resilience (adaptation), and reduces or removes greenhouse gas emissions (mitigation) where possible, while pursuing national food security and development goals [5]. Precision farming technologies constitute a critical operational layer of CSA, enabling data-driven, site-specific management decisions that optimise resource use efficiency and minimise environmental externalities [6,7].

Despite global momentum around CSA and precision agriculture, adoption in Nigeria and sub-Saharan Africa more broadly lags behind other regions. Barasa et al. [2] documented that most CSA activities on the continent remain at the policy and framework level, with limited grassroots implementation. In Nigeria specifically, Mbanasor et al. [1] identified low awareness, high input costs, and inadequate institutional support as principal barriers. This review addresses a gap in the literature by synthesising recent (2020–2025) empirical evidence on precision farming technologies through a CSA lens specific to Nigeria, evaluating both the performance of individual technologies and the systemic drivers of, and barriers to, adoption. The goal is to provide actionable insights for researchers, policymakers, and development practitioners committed to achieving food security in Nigeria.

2. METHODOLOGY

This study employed a structured narrative review methodology. Peer-reviewed articles, policy documents, and grey literature published between January 2020 and April 2025 were retrieved from PubMed/MEDLINE, Scopus, Web of Science, Google Scholar, and AGRIS databases. Search terms included: "climate-smart agriculture Nigeria", "precision farming sub-Saharan Africa", "UAV agriculture West Africa", "IoT sensors smallholder farming", "remote sensing crop monitoring Nigeria", and "food security technology adoption Nigeria". Inclusion criteria required English-language publications with empirical or review evidence relevant to CSA, precision farming technologies, or food security in Nigeria or comparable West/Central African contexts. A total of 35 references meeting these criteria were included in this synthesis, prioritising those with verifiable digital object identifiers (DOIs). Data were extracted on: technology type, application context, adoption level, productivity outcomes, and identified barriers. Results are organised thematically across sections 3 through 6.

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ISSN: 2456-8643

3. NIGERIA'S AGRICULTURAL LANDSCAPE AND CLIMATE VULNERABILITY

3.1 Agroecological Zones and Crop Systems

Nigeria encompasses six major agroecological zones, ranging from the humid mangrove forests of the Niger Delta to the semi-arid Sahel of the far north. This diversity sustains a broad range of staple and cash crops, including cassava, yam, maize, sorghum, millet, rice, cowpea, groundnut, cocoa, and oil palm, farmed predominantly by smallholders cultivating less than two hectares [1,8]. Over 85% of Nigerian farmers are smallholders characterised by rain-fed systems, low external input use, and limited access to mechanisation, credit, and information [2,9]. This structural vulnerability amplifies the agricultural sector's sensitivity to climate shocks.

Table 2 (below, in Section 5) maps climate hazards, priority crops, recommended CSA interventions, and expected outcomes across Nigeria's five major agricultural regions. The North-East faces the most severe drought and desertification pressure, threatening sorghum and millet production, while the coastal South is increasingly affected by flood events and salinity intrusion [3].

3.2 Climate Change Impacts on Food Security

Nigeria currently ranks among the most food-insecure nations globally, with approximately 25.3 million people in acute food insecurity as of 2023, according to the Cadre Harmonisé assessment. Climate change exacerbates underlying structural vulnerabilities: modelling studies project a 10–25% decline in yields of major staples under mid-century climate scenarios if no adaptive action is taken [3]. Alehile [10] demonstrated significant negative employment effects in Nigeria's agricultural sector attributable to climate change, with female smallholders disproportionately affected. Conservation agriculture, a foundational CSA practice involving reduced tillage, permanent soil cover, and crop rotation, has shown promise in arresting land degradation; Adetomiwa and Adeyera [11] documented improved soil moisture retention and carbon sequestration in Nigerian pilot plots, though adoption remained constrained by social norms and land tenure insecurity.

4. PRECISION FARMING TECHNOLOGIES IN THE CSA FRAMEWORK

Figure 1. Conceptual framework illustrating the integration of precision farming technologies within the three pillars of climate-smart agriculture (productivity, adaptation, mitigation) in Nigeria's agroecological zones.
Sources: Adapted from references [2,5,6,7,13].

4.1 Remote Sensing and Satellite-Based Monitoring

As shown in Figure 1, Remote sensing (RS) is among the most mature precision agriculture technologies available for resource-constrained contexts. Sishodia et al. [6] provided a comprehensive review of RS applications, demonstrating that multispectral and hyperspectral imagery enable high-accuracy assessments of crop health (via NDVI and EVI indices), soil organic matter, water content, and pest or disease pressure. In Nigeria, the Nigeria Soil Information Service (NiSIS) pilot, documented by Aduramigba-Modupe and Amapu [12], used RS-derived soil maps to guide site-specific fertiliser recommendations across selected states, a direct application of VRT principles. Free-to-access satellite products, including Sentinel-2 (10 m resolution) and Landsat-8 (30 m), have democratised RS access; however, cloud cover in the humid south and limited capacity for data interpretation remain significant constraints [4,6].

4.2 UAVs and Drone Technology

Unmanned aerial vehicles (UAVs) equipped with RGB and multispectral cameras offer sub-5 cm resolution imagery, enabling detection of field heterogeneity invisible to satellite platforms. Velusamy et al. [13] detailed UAV applications spanning canopy temperature mapping, spray coverage optimisation, and stand count estimation. In Nigeria, commercial drone service providers have emerged in the maize and cocoa belts, offering 'drone-as-a-service' (DaaS) models that reduce the capital barrier for smallholders [9]. However, regulatory ambiguity from the Nigerian Civil Aviation Authority (NCAA), high maintenance costs, and limited operator training capacity constrain widespread deployment.

4.3 IoT Sensors and Smart Irrigation

IoT-enabled sensor networks, measuring soil moisture, temperature, nutrient content, and atmospheric variables, provide real-time agronomic intelligence that supports precision irrigation and nutrient management. Abioye et al. [14] demonstrated that machine learning-integrated IoT irrigation platforms achieved water savings of 30–50% relative to conventional flood irrigation in West African trials. Saqib et al. [15] highlighted the critical role of edge computing in overcoming connectivity limitations in rural areas. In Nigeria, IoT-based greenhouse pilots in Ogun and Oyo states and sensor-guided irrigation in Kebbi Valley rice schemes have demonstrated feasibility, yet grid electricity unreliability and internet connectivity deficits impede scalability. The federal Energising Agriculture Programme (EAP), which deploys decentralised renewable energy for agriculture, could synergistically power IoT infrastructure in off-grid farming communities.

4.4 Variable Rate Technology (VRT) and AI-Based Decision Support

VRT enables GPS-guided machinery to apply seeds, fertilisers, pesticides, and irrigation water at spatially variable rates calibrated to field-level data layers. When integrated with AI and machine learning, VRT systems can learn from in-season crop response data to refine prescriptions iteratively [7,16]. Ringler et al. [17] argued that AI-powered precision food systems represent a step-change in the capacity to optimise food security outcomes under climate variability. In Nigeria, VRT adoption is currently limited to large commercial farms and government-supported demonstration plots. The NiSIS soil mapping project [12] provides the foundational spatial data needed to operationalise VRT prescriptions, and NATIP explicitly mandates the integration of these technologies into extension services.

4.5 Mobile and Digital Advisory Services

Given the constraints on hardware adoption, mobile-based digital advisory platforms represent the most scalable and cost-effective precision farming entry point for Nigerian smallholders. Platforms such as Farmcrowdy, Hello Tractor, and Samada Agro deliver agronomic advice, mechanisation services, and market price information via SMS or app interfaces. McCampbell and Simelton [18] cautioned, however, that digital climate services do not automatically translate to behaviour change unless they are co-designed with farmers and embedded in trusted extension networks. Abdulrahaman and Bello [19] similarly identified digital literacy, language barriers, and lack of local content as constraints to digital advisory uptake among Nigerian farmers. Table 1 shows the Summary of Precision Farming Technologies and Their Application in Nigeria's CSA Context.

Table 1. Summary of Precision Farming Technologies and Their Application in Nigeria's CSA Context

Technology	Description / Function	Nigeria Application	Key Benefit	Adoption Level
Remote Sensing (RS)	Satellite/aerial imagery for crop monitoring, soil mapping, yield estimation	NDVI-based crop health assessments; NiSIS soil fertility mapping pilot	Early stress detection; soil nutrient mapping	Low–Moderate
UAVs / Drones	Unmanned aerial vehicles equipped with multispectral cameras and GPS	Crop scouting in maize/cassava belts; emerging commercial drone-as-a-service models	High-resolution field mapping; targeted pesticide application	Emerging
IoT Sensors	Soil moisture, temperature, humidity sensors linked to cloud analytics	Smart irrigation pilots in Kebbi, Kano; greenhouse sensors in the South-West	Real-time decision support; water use efficiency	Low
Variable Rate Technology (VRT)	GPS-guided machines that apply inputs (fertiliser, seed, water) at variable rates across fields	Limited to large-scale commercial farms; integrated with NATIP 2022–2027	Reduces input waste; optimises yield per hectare	Very Low

Technology	Description / Function	Nigeria Application	Key Benefit	Adoption Level
AI / Machine Learning	Predictive analytics for pest forecasting, yield modelling, disease detection	Pilot projects in cassava disease detection; digital advisory apps (e.g. PlantVillage)	Scalable decision support; reduced crop losses	Nascent
Mobile/Digital Advisory	SMS/app-based agronomic advice, weather alerts, market information	Farmcrowdy, Hello Tractor, Samada Agro widely used among smallholders	Accessible to low-literacy farmers; low cost	Moderate

Note: Adoption levels rated as: Very Low (<5%), Low (5–15%), Moderate (15–35%), Emerging (nascent commercial deployment).

5. REGIONAL CSA PRIORITIES AND PRECISION TECHNOLOGY LINKAGES

Nigeria's agroecological diversity necessitates differentiated CSA strategies. Recha et al. [20] emphasised that technology recommendations must be contextualised to local biophysical and socioeconomic conditions to achieve maximum impact. Mzezewa et al. [4] similarly documented how traditional farmers in south-eastern Nigeria have historically adapted to climate variability through intercropping, agroforestry, and seasonal migration—practices that can be enhanced but not replaced by digital technologies.

In the arid north, drought-tolerant crop varieties, including IITA-developed drought-tolerant maize (DT-Maize) and improved cowpea germplasm, form the cornerstone of CSA. RS-guided planting window optimisation and IoT soil moisture monitoring can substantially improve their performance under variable rainfall [2,20]. In the Middle Belt, where both flood and drought occur within the same season, GIS-based land management and mobile advisory platforms providing flood risk alerts are particularly valuable [3]. In the humid south, UAV-based canopy monitoring of cocoa and oil palm plantations, integrated with AI pest detection models, is emerging as a commercially viable precision farming application [13,21]. Table 2. Regional Climate Hazards, Crops at Risk, and Recommended CSA–Precision Farming Interventions by Agroecological Zone. While Figure 2 gives the Map of Nigeria's six agroecological zones annotated with dominant precision farming technologies deployed or recommended per zone, primary climate hazards, and CSA adoption level.

Table 2. Regional Climate Hazards, Crops at Risk, and Recommended CSA–Precision Farming Interventions by Agroecological Zone

Region (Nigeria)	Primary Climate Hazard	Key Crops at Risk	CSA Intervention	Expected Outcome
North-East (Sahel)	Severe drought, desertification	Sorghum, millet, cowpea	Drought-tolerant varieties; soil	20–35% yield improvement

Region (Nigeria)	Primary Climate Hazard	Key Crops at Risk	CSA Intervention	Expected Outcome
			moisture sensors; conservation tillage	under water stress
North-West (Sudan Savannah)	Erratic rainfall, heat stress	Maize, groundnut, wheat	Precision irrigation; AI-based seasonal forecasting; fertiliser VRT	Water savings of up to 40%; reduced input cost
Middle Belt (Guinea Savannah)	Flood–drought cycles, land degradation	Cassava, yam, maize, rice	Agroforestry integration; GIS-based soil mapping; mobile advisory platforms	Improved soil organic carbon; 15–25% yield gain
South-West (Derived Savannah)	Deforestation, irregular wet seasons	Cocoa, cassava, plantain, vegetables	UAV canopy monitoring; intercropping with shade trees; precision pest control	Reduced pesticide use by 30%; improved cocoa quality
South-East / South-South (Rainforest)	Flooding, soil erosion, coastal salinity intrusion	Oil palm, yam, rice, vegetables	Remote sensing for flood mapping; salt-tolerant rice varieties; biochar soil amendment	Flood risk reduction; soil fertility restoration

Sources: Data Synthesised from references [1,2,3,4,8,12,20].

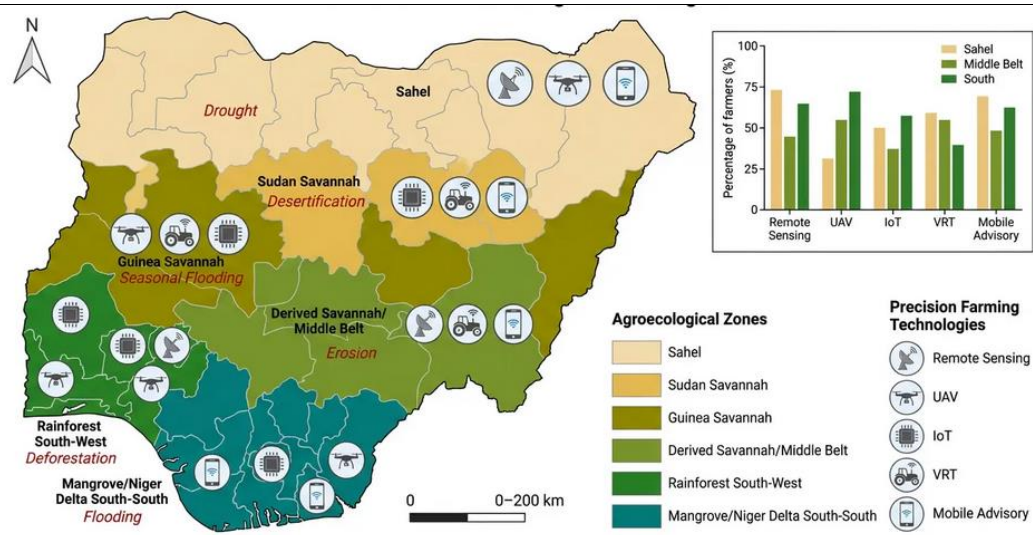

Figure 2. Map of Nigeria's six agroecological zones annotated with dominant precision farming technologies deployed or recommended per zone, primary climate hazards, and CSA adoption level.

Sources: Figure Synthesised from references [1,4,6,12,20].

6. BARRIERS AND ENABLING CONDITIONS FOR CSA ADOPTION IN NIGERIA

6.1 Barriers to Adoption

The adoption of precision farming technologies by Nigerian smallholders is impeded by a constellation of structural, institutional, and behavioural barriers. Capital cost is the most widely cited impediment: a basic drone-and-sensor kit suitable for field monitoring can cost ₦2–5 million, equivalent to five or more years of income for a typical smallholder [1,22]. Infrastructure deficits, unreliable electricity, poor internet connectivity, and inadequate road networks for equipment access, compound the cost barrier [8,10]. Low digital literacy, particularly among older and female farmers, restricts meaningful engagement with digital advisory platforms [19]. Land tenure insecurity discourages investment in site-specific management infrastructure, as farmers on insecure tenancies have little incentive to invest in long-term soil data collection [11,23]. At the institutional level, Agyekum et al. [22] identified weak extension systems, absence of CSA-specific financing instruments, and limited government budget execution as systemic barriers in West Africa broadly applicable to Nigeria.

6.2 Enabling Conditions and Emerging Opportunities

Several enabling conditions offer credible pathways for accelerated CSA and precision farming adoption in Nigeria. The NATIP 2022–2027 explicitly incorporates precision agriculture, digital extension, and e-agriculture as strategic priorities, providing a policy anchor for technology deployment [12]. Nigeria's youthful demographics, approximately 70% of the population is under 35, create a ready cohort of tech-savvy early adopters amenable to digital farming tools [8,9]. The proliferation of affordable smartphones and expanding 4G coverage in secondary cities is extending digital connectivity into peri-urban farming communities. Public–private partnerships between agri-tech startups and federal/state agricultural development programmes (ADPs) are scaling digital advisory services at low cost. Amoak et al. [24] demonstrated that integrating climate information into extension frameworks significantly increased adoption of climate-resilient practices, a model transferable to the Nigerian context. Cooperative farming structures, documented by Akinola et al. [25], offer collective procurement pathways that can reduce per-farmer technology acquisition costs substantially.

7. POLICY AND INSTITUTIONAL FRAMEWORK FOR CSA SCALE-UP

A conducive policy environment is essential for the transition from demonstration-scale pilots to systemic adoption of precision farming under a CSA framework. Table 3 summarises the key policies and programmes relevant to CSA and precision farming in Nigeria, their implementing bodies, and principal gaps.

Table 3. Key Policy Instruments and Programmes Supporting CSA and Precision Farming Adoption in Nigeria

Policy / Programme	Implementing Body	Relevance to CSA / Precision Farming	Key Gap / Challenge	Period
National Agricultural Technology and Innovation Policy (NATIP)	Federal Ministry of Agriculture	Explicitly mandates precision agriculture, digital advisory systems, and e-agriculture nationwide	Low capital budget utilisation (~17% of target in 2022–2024)	2022–2027
Nigeria Nationally Determined Contributions (NDC)	Federal Ministry of Environment	Links food security with climate adaptation and mitigation; supports CSA mainstreaming	Insufficient alignment with sectoral CSA investment plans	2021–2030
Anchor Borrowers' Programme (ABP)	Central Bank of Nigeria	Subsidised farm inputs and finance that can be leveraged for technology adoption by smallholders	Limited digital literacy among beneficiaries; high default rates	2015–ongoing
Nigeria Soil Information Service (NiSIS)	FMARD / IITA	Digital soil fertility mapping to guide site-specific nutrient management via VRT and mobile advisory	Coverage limited to pilot states; lacks farmer-level outreach	2020–ongoing
Energising Agriculture	Rural Electrification	Decentralised renewable energy to	Slow deployment;	2020–ongoing

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ISSN: 2456-8643

Policy / Programme	Implementing Body	Relevance to CSA / Precision Farming	Key Gap / Challenge	Period
Programme (EAP)	Agency	power IoT sensors, irrigation pumps, and cold-chain equipment	rural connectivity deficit persists	

Sources: compiled from references [1,8,9,10,12].

Despite the existence of supportive policies, implementation remains the principal bottleneck. The NiSIS pilot [12] illustrates the potential of government-led precision data infrastructure, but scale-out requires sustained budget allocation and farmer-facing dissemination channels that presently do not exist at national scale. The NDC Action Plan's alignment with NATIP is encouraging, but without dedicated CSA financing, such as a green agricultural bond facility or climate-linked concessional credit, private investment will remain insufficient to bridge the technology access gap for smallholders [3]. Mazengia et al. [9] and Cooke et al. [26] both highlight the importance of participatory technology design, gender-responsive extension, and local capacity building in achieving durable CSA adoption in sub-Saharan Africa.

8. FUTURE DIRECTIONS AND RESEARCH PRIORITIES

This review identifies several priority research and development areas for CSA and precision farming in Nigeria. First, there is an urgent need for the development and validation of low-cost, rugged sensor platforms optimised for Nigeria's climate zones, power constraints, and connectivity landscapes. Affordable soil moisture sensors powered by solar micro-panels and transmitting via LPWAN (LoRa) networks represent a particularly promising convergence of existing technologies. Second, AI-driven disease and pest detection models trained on Nigerian crop and pathogen datasets—rather than transferred from temperate-climate training data—would dramatically improve applicability [13,14,17]. Third, social science research is needed to understand gender-differentiated adoption pathways, the role of farmer organisations in collective technology procurement, and the behavioural economics of digital advisory uptake in low-literacy contexts [19,22,24]. Fourth, integrated assessments linking precision farming adoption to greenhouse gas mitigation co-benefits would strengthen the case for climate finance directed at Nigerian agriculture [3]. Fifth, rigorous impact evaluation studies, using randomised controlled trials or quasi-experimental designs, are needed to quantify the food security, income, and resilience effects of precision farming at household and community levels across Nigeria's diverse agroecological zones [1,21].

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ISSN: 2456-8643

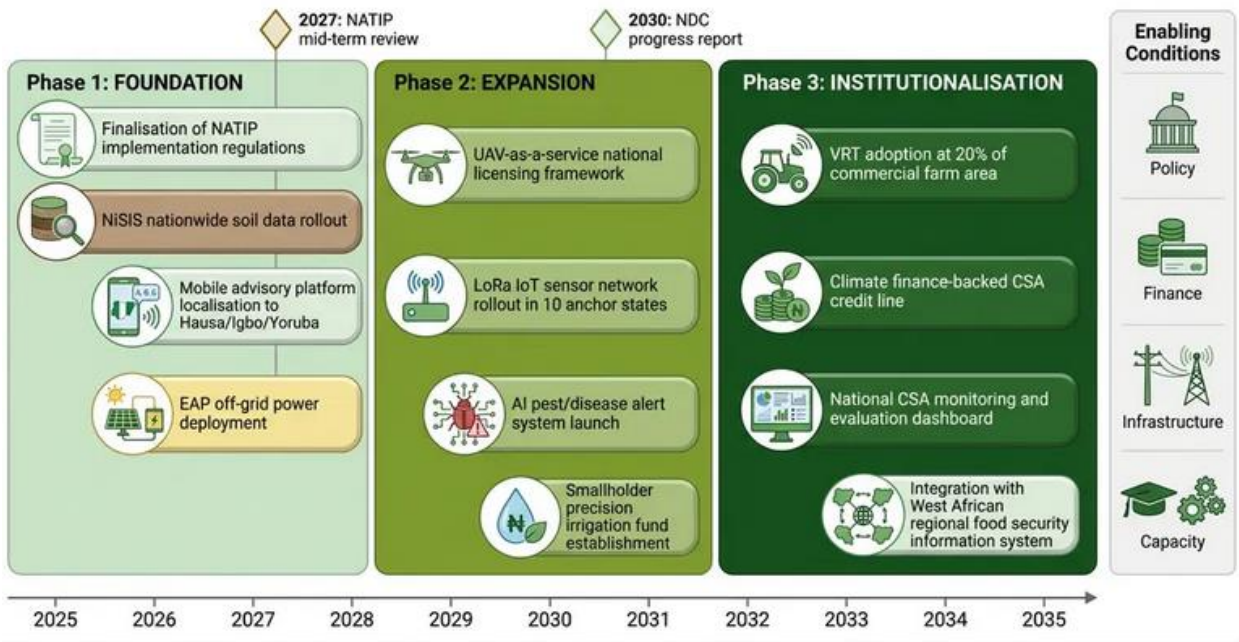

Figure 3. Conceptual roadmap for scaling climate-smart precision agriculture in Nigeria (2025–2035), illustrating phased implementation milestones, technology readiness levels, and policy enablers.

Sources: Adapted from references [3,8,12,22]

9. CONCLUSION

Climate-smart agriculture, operationalised through precision farming technologies, offers a scientifically grounded and practically viable pathway to address Nigeria's intertwined challenges of food insecurity, climate vulnerability, and natural resource degradation. This review has demonstrated that while the individual performance of remote sensing, UAVs, IoT sensors, VRT, and AI-based decision support is well-documented globally, adoption in Nigeria remains nascent, constrained by structural infrastructure gaps, high technology costs, weak institutional capacity, and fragmented policy implementation. The most tractable near-term entry points are mobile digital advisory services, community-level IoT irrigation systems, and UAV-based crop monitoring services delivered through DaaS business models. In the medium term, the full potential of precision farming for CSA will only be realised through sustained policy financing, public–private investment in rural digital infrastructure, farmer co-design of context-appropriate technologies, and robust monitoring and evaluation frameworks. Nigeria's policy architecture, particularly NATIP 2022–2027 and the NDC Action Plan, provides a credible foundation. The imperative now is to accelerate implementation, attract green climate finance, and centre the smallholder farmer as the primary beneficiary and co-creator of precision CSA innovation.

Declarations

Funding:

This research received no external funding.

Conflicts of Interest:
The author declares no conflict of interest.
Data Availability:
Not applicable (review study**).**

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ISSN: 2456-8643

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