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DATA-DRIVEN INNOVATION IN AGRICULTURE: A CRITICAL IMPERATIVE FOR FOOD AND NUTRITION SECURITY IN SUB-SAHARAN AFRICA

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ABSTRACT

Sub-Saharan Africa (SSA) faces persistent challenges in achieving sustainable agricultural production and food and nutrition security. Traditional farming methods, climate change, poor infrastructure, obsolete technology, declining resources, and limited access to finance and markets, are factors exacerbating these problems. Meanwhile, availability of reliable and accurate data is crucial for efficient resource allocation and management in critical sectors of developing countries, including agriculture. In countries where resources are scarce, efficient resource use will not only reduce waste but also ensure appropriate prioritization of the countries' developmental needs. Development will forever remain a mirage in countries where there are no accurate data to learn from the past, manage the present sustainably, and understand the future trajectories of problems and prospects for accelerated progress in key sectors. This paper adopts a nuanced approach to explore how accurate agricultural data and innovation jointly influence food security in Africa. The methodology follows a multistage process, beginning with an extensive search of peer-reviewed journals, policy documents, and regional case studies to establish a rigorous evidence base. It then provides careful contextualisation, drawing on credible sources and relevant examples within and beyond Africa to clarify key concepts and terminologies. Through this approach, the study identifies the core problem, unravels knowledge gaps, and highlights issues often overlooked in the literature. In SSA, data-driven innovations have been documented to assist in strengthening resilience against climate shocks and other agriculture-related risks through the facilitation of tailored advisory services, predictive analytics and early warning systems. The availability and accessibility of technologies that combine weather forecasts, soil data, and historical yield trends can help farmers to be proactive in planning for climatic risks, optimizing planting schedules, and improving crop yields. Also, data-enabled platforms are transforming access to credit and insurance through digital profiling and risk assessment models that evaluate farm-level data to determine creditworthiness and underwrite agricultural insurance more effectively. Thus, data-driven approaches leveraging advances in technology such as remote sensing, mobile platforms, big data analytics, and precision agriculture offer transformative opportunities in these countries. The productivity improvement and social inclusion objectives of the government and relevant stakeholders can only be achieved with accurate and timely data. The paper concludes by highlighting the prime place of data-driven innovation in agricultural sustainability for improved nutrition and food security as well as the key initiatives and policy re-engineering required to transform African food systems in general.

Key words: Data, Africa, Sustainability, Agriculture, Digital technology, Food security

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INTRODUCTION

Data-driven innovation in agriculture refers to the use of data analytics, digital technologies, and machine learning to increase agricultural productivity, sustainability and profitability [1]. According to Raji and Njoku [2], this process involves collecting, analysing and using data from various sources to inform decision-making across the entire agricultural value chain. Sub-Saharan Africa (SSA) is undergoing rapid demographic growth, with the population expected to double by 2050 [3]. The region is home to some of the world's fastest-growing populations [4, 5]. However, the region remains heavily dependent on rainfed agriculture characterized by low productivity and high vulnerability to climate shocks. Achieving sustainable food production is critical for the socioeconomic development and food security of SSA. Data-driven innovation in agriculture presents an unprecedented opportunity to transform the sector. By integrating data collection, analysis and dissemination into farming practices, agricultural stakeholders can make informed decisions and optimize resources while preserving natural resources and ultimately improving food and nutritional security [1, 2].

Strategic data collection provides an opportunity for policy makers to understand the needs of citizens and the best policy varieties to address their needs. For example, data on current productivity per hectare cultivated by smallholder farmers, average climatic conditions, and their existing practices will guide key stakeholders in determining the best varieties of crop and strains of livestock. Also, productivity improvement interventions such as training and extension, artificial insemination, farm-level packaging and processing, and partnerships will provide the necessary impetus required to achieve food security and income maximization objectives.

According to the Advanced Oxford Learners' Dictionary [6], data are facts or information, especially when they are examined and adopted to find, analyse and evaluate things or to make decisions. When analysing and evaluating data, resilience is the pathway for assessing key players or systems that could overcome uncertainties resulting from natural events or adverse climate change impacts [7]. Ifejika [8] describes it as the ability to respond to distortions or cope with uncertainties while maintaining the same structure to achieve economic development, productivity improvement and social objectives.

On the other hand, food security is a situation in which people always have economic and physical access to safe and nutritious food in sufficient quantities to meet their dietary needs and food preferences for an active and healthy life [9]. Similarly, nutrition security is defined by the Committee on World Food Security (CFS) [10] as a condition in which all people at all times consume food of sufficient quantity and quality in terms of variety, diversity, nutrient content, and safety to meet their dietary



needs and food preferences for an active and healthy life within the context of a sanitary environment, adequate health and care. Therefore, the concepts of food and nutrition security were combined to emphasize the complementarity and overlaps between nutrition and food security [11].

Specifically, food and nutrition security cover a situation in which sufficient food (quality, quantity, safety and sociocultural acceptability) is accessible and available for, and satisfactorily, always utilized by all individuals to live a healthy and happy life [12, 13]. This paper, therefore, discusses the importance of relevant and accurate data in agricultural transformation, presents case studies of successful initiatives, and outlines recommendations for scaling up data-driven agricultural solutions in SSA.

THE STATE OF AGRICULTURE, FOOD AND NUTRITION SECURITY IN AFRICA

Agriculture is integral to Africa's economy, employing a significant portion of the population and contributing substantially to the gross domestic product (GDP). However, Africa's agricultural sector faces multifaceted challenges that hinder its potential to ensure food security and drive economic growth. As of 2023, agriculture accounted for an average of 18.74% of GDP across 45 SSAs [14]. While this average masks the actual contribution of the sector to an individual country's GDP, it is important to note that the role of agriculture cannot be overestimated, as it employs approximately 42% of the total labour force and is the main source of livelihood for poor people [15]. In most cases, a declining share of agricultural GDP is the result of rapid growth in non-agricultural sectors, whereas increases in the contribution of agriculture to national GDP stem from either the growth of agricultural value added or, more commonly, from declines in non-agricultural sector output [14, 15].

Moreover, despite the dwindling contribution of agriculture to the economy of Africa, the importance of agriculture on the continent cannot be overemphasized. This is because agriculture remains a source of livelihood for more than 66.7% of Africa's growing population. According to the Organisation for Economic Cooperation and Development/ Food and Agriculture Organization [16], agriculture contributes approximately 15% of the continent's gross domestic product (GDP), and it is the foundation for achieving at least five of the 17 sustainable development goals (SDGs). For example, Goals 1--5, which focus on no poverty, zero hunger, good health and well-being, gender equality and quality education, cannot be achieved without robust and resilient agriculture, which is a prerequisite for achieving food and nutritional security.



Agriculture therefore, remains an indispensable sector to Africa's socioeconomic fabric, supporting more than two-thirds of the continent's population. In South Africa, for example, the critical role of agriculture cannot be downplayed. It contributes approximately 3.0% of the country's GDP as indicated by Global African Network [17]. The agricultural sector of South Africa is also the main employer of residents of rural areas, and most of the developmental initiatives of the government, as coined in the National Development Plan (NDP), hinge on agriculture as the driver or enabler. The agricultural sector in the Limpopo Province of South Africa, for instance, contributes approximately 7.6% to national agriculture, with a provincial GDP contribution of approximately 2.3% [17]. The fruits and vegetables produced in Limpopo Province constitute an important part of South Africa's export basket, and more than 45.0% of the annual turnover of the Johannesburg Fresh Produce Market originates in this fertile province.

Moreover, the full potential of agriculture is hindered by multiple challenges, including unreliable data, climate risks, pest invasions, and macroeconomic instability. Abdella [18] reported that of the 7.2 billion people globally, over 2 billion do not have access to safe, nutritious or sufficient food. The lack of credible and reliable data needed for planning has led agriculture, the primary source of food to perform below its potential regarding its contribution to Africa's economic growth through the provision of much-needed jobs and industrial transformation. According to AGRA [19], despite Africa being home to nearly 60% of the world's uncultivated arable land, the continent remains a net food importer, as it spends billions annually to meet its food demands. Guardian [20] food insecurity projections indicate that by 2030, Africa will surpass Asia in terms of the number of people facing hunger, with over 600 million Africans expected to suffer from chronic food insecurity.

Some of the challenges impeding agricultural resilience in Africa include technology inadequacy, adverse impacts of climate change, a high incidence of pests and diseases, unstable micro- and macroeconomic variables and other unforeseen shocks that often lead to limited food sources and food scarcity, which places severe strain on the food distribution network. Thus, having robust and resilient agriculture requires a conscious and deliberate effort to obtain a solid and reliable database where important information required for planning and transforming agriculture for development is available and accessible. The Organisation for Economic Cooperation and Development [21] posits that sound and timely data and statistics are essential for designing better policies for better lives. This is because when the right data are available and used by policy makers, they play a pivotal role in managing and mitigating shocks in agriculture.



THE KEY CHALLENGES TO AGRICULTURE IN AFRICA

Farming is a way of life for millions of people in Africa, but it comes with many tough challenges. Most farmers work on small plots of land and often rely on simple tools and age-old techniques passed through generations. Without accurate data, access to modern equipment, quality seeds, or reliable irrigation, it is difficult for them to grow enough food or earn a steady income. Poor roads and storage also mean that even when farmers have good harvests, many of them can spoil before they reach the market. These daily struggles make it difficult for families to break the cycle of poverty, even when they work tirelessly on land.

In addition, climate change is making things even harder. Rainy seasons have become unpredictable, and droughts or floods can wipe out crops in a matter of days. The land that is once producing enough to feed a family slowly becomes less fertile because of overuse and environmental damage. Many farmers also face uncertainty around land ownership and do not have the support they need from governments or financial institutions. To build a stronger future for African agriculture, it is essential to support farmers with better tools, fair policies, and the ability to adapt to a changing climate. The following are some of the key challenges that face agriculture in Africa.

Low productivity

According to the Food and Agriculture Organization [22], agricultural productivity in SSA remains among the lowest globally. Cereal yields average only 1.5 tons per hectare, whereas the global average is 3.9 tons [22]. Most farmers in Africa depend on traditional methods, limited mechanization, and insufficient input use. This productivity gap undermines food availability and economic competitiveness. Across many African farms, hardworking farmers pour their energy into the soil, yet the harvest often falls short of their effort. Outdated tools, limited access to improved seeds and fertilizers, and little exposure to modern farming techniques make it difficult to produce enough food for growing communities. As a result, families struggle to earn a stable income, and local markets lack the food and nutrition needed to nourish the population. Despite their determination, farmers are trapped in a cycle where low productivity limits both progress and hope.

Climate vulnerability

For millions of farmers in Africa, agriculture relies heavily on rain and predictable weather. However, today, the climate is experiencing increasingly unpredictable rains that occur too late or too much at once, and long droughts destroy crops and livestock. Flooded fields, barren land and rising temperatures make it harder to grow food or keep animals healthy. When crops fail, families become hungry, incomes drop, and whole communities become more vulnerable to malnutrition. Climate



change is no longer a distant threat; it is an everyday struggle that puts food security and nutrition at risk. Frequent droughts, floods and unpredictable rainfall patterns in Africa increasingly disrupt agricultural production cycles, including planting and harvesting cycles. The dependence on rain-fed agriculture further exposes farmers to climate-related shocks and compromises yields and income stability [23].

Limited access to agricultural inputs (production assets)

The availability and affordability of essential inputs such as quality seeds, fertilizers, and farming equipment remain major challenges for farmers in Africa, as many of them find it difficult to access credit or extension services [24], which exacerbates input inefficiencies in Africa. Even when farmers know how to improve their farms, they often cannot obtain the tools they need to do so. Improved seeds, fertilizers, irrigation equipment, and farming machinery are either too expensive or simply unavailable in nearby markets. Without these essential inputs, crop yields remain low, and farmers are unable to produce enough food to feed their families or supply local markets. This lack of resources keeps communities trapped in hunger and poverty, making it difficult to access nutritious food and build a secure future. For many, the desire to grow more is there, but the means to do so are painfully out of reach.

Inadequate infrastructure

Rural areas of Africa often lack functional road networks, electricity, cold storage and market facilities [25]. These infrastructural gaps result in postharvest losses and limit farmers' access to local and regional markets. Even when farmers manage to grow enough food, poor infrastructure can undo their hard work. Bad roads make it difficult to transport crops to markets, and without proper storage facilities, much of the harvest spoils before reaching consumers. Limited access to electricity and clean water makes processing, preservation and irrigation a constant challenge. These gaps in infrastructure isolate rural communities, increase food prices, and limit access to nutritious food. In the end, the lack of basic facilities hinders agriculture, weakens nutrition, and exacerbates food insecurity across the continent.

Information asymmetry

In many rural communities across Africa, farmers wake up every day to tend their crops without access to the information that could help them succeed. They often do not know which seeds are best for their soil, when to plant for the best yields, or how to protect their crops from new pests and diseases. Moreover, traders and middlemen often have advantages in terms of market prices and trends, leaving farmers at a disadvantage when selling their produce. This gap in knowledge and access to trusted information means that many hardworking farmers continue to struggle with low yields and poor incomes, and ultimately, families go without the



nutritious food they need. Smallholder farmers in Africa often operate in information-poor environments. They lack access to timely data on weather forecasts, pest outbreaks, market demand, and pricing, which limits their ability to make informed decisions and harness opportunities [26].

Climate change impacts

Climate change poses one of the most pressing threats to agriculture in SSA. The region is warming at a faster rate than the global average, with average surface temperatures rising steadily over the past decades [27]. This has led to severe disruptions in rainfall patterns, more frequent droughts, delayed planting seasons, floods, and extreme weather events that significantly affect both crop and livestock production. Climate-related losses in SSA range between \$7 billion and \$15 billion annually, with projections estimating an increase to \$50 billion by 2030 if no robust adaptation mechanisms are implemented [23].

Rising temperatures and shifting ecological zones have led to increased pest and disease outbreaks, threatening food systems and undermining productivity [28]. Crops such as maize, wheat, and beans are particularly vulnerable, with significant yield declines already reported in several countries [29]. Livestock productivity is also declining due to heat stress and shrinking grazing areas.

The situation is exacerbated by limited investment in climate-resilient infrastructure, weak early warning systems, and the underutilization of climate-smart agricultural practices [29]. Strengthening adaptation through better forecasting, resilient crop varieties, agroforestry, and irrigation systems is essential. Regional cooperation, supported by data and technology, will be key in mitigating climate shocks and building long-term resilience across agricultural value chains.

Soil degradation

In a study by Zingore *et al.* [30], soil degradation was a critical concern in SSA, with an estimated 65% of the region's agricultural land degrading due to erosion, nutrient depletion, salinization and acidification. This degradation severely compromises agricultural productivity, food security and the livelihoods of millions of smallholder farmers who depend on the land. The key drivers of soil degradation include overcultivation, deforestation, unsustainable land use practices, and overgrazing, all of which reduce organic matter and soil fertility [31].

The consequences are far-reaching. Reduced soil health limits the capacity of crops to grow effectively, compels farmers to expand into marginal lands, and increases the risk of further environmental damage [31]. Additionally, poor soil quality reduces water retention, increasing the vulnerability of crops to drought and other climatic stresses. Despite the severity of the problem, efforts to address soil degradation



remain fragmented. However, continental initiatives such as the Nairobi Declaration on Sustainable Soil Management aim to reverse this trend through the promotion of conservation agriculture, agroecological approaches, composting, crop rotation, and integrated soil fertility management [32].

Trade and market access

Agricultural trade and access to markets in SSA remain constrained by systemic barriers despite the sector's central role in food security and rural livelihoods. As indicated by the African Union Commission [33], intra-African agricultural trade stands at less than 15% as of 2022, contrary to the commitments outlined in the 2014 Malabo Declaration, which aimed to triple such trade by 2025. Limited infrastructure, nontariff barriers, fragmented regulatory frameworks, and a lack of harmonized standards continue to impede trade flows within the continent. Smallholder farmers, who produce a significant share of Africa's agricultural produce, often face high transportation costs, poor access to storage facilities, and limited market information, preventing them from reaching lucrative markets [34]. The dominance of informal markets, which lack quality control mechanisms and financing opportunities, further restricts scalability and competitiveness.

Nonetheless, the African Continental Free Trade Area (AfCFTA), launched in 2021, presents a transformative opportunity to overcome these obstacles [35]. By reducing tariffs, standardizing policies, and integrating markets, the AfCFTA can bolster regional trade, stimulate agricultural diversification, and increase farmer incomes [35]. For the potential of the AfCFTA to be fully realized, governments must invest in rural infrastructure, upgrade border facilities, improve logistics, and enhance digital trade platforms. Empowering farmer cooperatives and supporting data-driven trade mapping can also improve transparency, competitiveness, and food distribution across a region.

Agricultural information gaps

Access to accurate, timely and localized agricultural information remains a major barrier to progress in SSA. Many smallholder farmers in the region operate without knowledge of evolving weather patterns, pest and disease outbreaks, soil health conditions, or current market prices. This information asymmetry limits their ability to make sound decisions regarding planting schedules, crop choices, irrigation, and selling times, ultimately affecting productivity and profitability. Traditional extension services, which are expected to bridge these gaps, are often underfunded, understaffed, and inefficient, especially in rural and remote areas [26]. Moreover, there is a lack of integration among agricultural research institutions, data providers, and farmers. Consequently, innovations generated by research rarely reach those that need them most.



Digital technologies present a transformative solution. Mobile applications, radio, SMS alerts, and online platforms can disseminate critical agricultural information at scale. For example, real-time weather forecasts, early warning systems, and market intelligence can help mitigate risks and increase efficiency. However, digital divide issues such as low smartphone penetration, limited internet coverage, and poor digital literacy remain challenges [36]. To address these gaps, governments and development partners must strengthen their digital infrastructure, invest in agricultural research and extension services, and promote partnerships between team developers and local farming communities. A coordinated, data-driven information system is essential for sustainable agricultural transformation in SSA.

OPPORTUNITIES AND PATHWAYS FOR AGRICULTURE TRANSFORMATION

Technological advancements

Technological innovations present significant opportunities to revolutionize agriculture in SSA. Precision agriculture, powered by Global Position System (GPS), remote sensing, and Internet of Things (IoT) devices, enables farmers to optimize the use of water, fertilizers and pesticides, significantly improving yields while reducing costs [37]. Mobile platforms allow smallholder farmers to access weather forecasts, market prices, extension advice, and financial services in real time [38]. Mechanization through automated machinery, such as GPS-guided tractors, can alleviate labor shortages and increase land productivity. Artificial intelligence (AI) and machine learning applications are being deployed to predict crop yields, detect diseases early, and guide planting decisions [37]. These tools empower data-informed decisions, reducing risk and postharvest losses. Furthermore, innovations such as drone technology help monitor crop health and plan field operations with greater efficiency [39]. However, the full potential of these advancements depends on infrastructure readiness, affordability, and user training. Scaling digital agriculture can close productivity gaps, improve food security, and accelerate inclusive agricultural transformation across SSA.

Empowering women and youth

Women and youth are central to Africa's agricultural workforce, yet they often face systemic exclusion from resources, decision-making, and opportunities. As indicated by the FAO [40], empowering these groups is not just a moral imperative; it is also a necessity for development. Women perform more than 50% of agricultural labor in SSA but own less than 15% of land and receive only 10% credit [41]. Closing this gap through gender-responsive policies, access to finance, land rights reform, and inclusive extension services could significantly increase agricultural productivity [42]. Similarly, youth make up more than 60% of Africa's population and face high unemployment rates. Equipping youth with digital skills, entrepreneurial training, and



access to agri-tech startups and agribusiness incubation hubs can unlock their innovation potential [43]. Programs such as “Agrihack” and “eYouth Farm” illustrate how technology can engage youth in farming. Inclusive interventions targeting these demographics will not only bolster food production but also rejuvenate the sector with creativity, adaptability, and long-term resilience, ensuring intergenerational transformation [44].

Sustainable practices

To ensure long-term productivity, ecosystem health, and climate resilience in SSA, sustainable agricultural practices are critical. Climate-smart agriculture (CSA), agroecology, and conservation agriculture are gaining momentum as alternatives to unsustainable conventional methods [32, 40]. Climate-smart agriculture promotes integrated soil fertility management, crop diversification, and drought-tolerant seed varieties that reduce greenhouse gas emissions and increase resilience to climate shock. The integration of agroecology blends scientific knowledge with indigenous practices, preserving biodiversity while increasing yields through natural soil and pest management. Conservation agriculture emphasizes minimal soil disturbance, permanent soil cover, and crop rotations to restore degraded lands [40]. These approaches reduce erosion, improve water retention, and rebuild organic matter. Moreover, the expansion of organic farming presents a significant opportunity to meet the growing demand for chemical-free produce and align with international export standards. When coupled with digital tools for monitoring sustainability metrics such as carbon sequestration and water usage, these practices can attract climate finance and green investments [45]. Promoting sustainability ensures food security and environmental integrity for current and future generations.

Data infrastructure and digital inclusion

Robust data infrastructure is the backbone of a thriving digital agricultural ecosystem in SSA. Timely, accurate, and disaggregated data enable better decision-making at all levels, from individual farmers to national policymakers. Harnessing geospatial technologies, including remote sensing and on-farm sensors, creates opportunities for advancing predictive tools in agriculture, such as yield estimation, pest detection, and early warning systems [39, 45]. These innovations can significantly increase productivity and reduce risks. However, the effectiveness of such digital tools is constrained by inadequate connectivity in many rural regions. Addressing these digital divides requires targeted strategies that improve internet infrastructure, lower the cost of smart technologies, and build digital competencies among farming communities to ensure inclusivity in data-driven agriculture. Public–private partnerships (PPPs) can fund broadband rollouts, mobile-enabled extension services, and localized agricultural platforms. Initiatives such as Digital Green and PlantVillage demonstrate the value of open-access data and localized advisory



systems [46, 47]. Furthermore, ensuring data governance, privacy, and farmer consent is essential for trust and participation. Strengthening data systems enhances transparency, reduces inefficiencies, and increases resilience in food systems, making agriculture smarter, adaptive and inclusive in the face of climate and market uncertainties.

Institutional and policy support

Effective institutional frameworks and enabling policies are foundational to agricultural transformation in SSA. Weak institutions, inconsistent policies, and bureaucratic delays hinder technology adoption, investment, and innovation. Governments must prioritize agricultural policy coherence, resource allocation, and cross-sector coordination. For example, aligning national strategies with regional frameworks, such as the Comprehensive Africa Agriculture Development Programme (CAADP) and the Malabo Declaration, has strengthened collective progress [33]. Policy instruments should incentivize agritech adoption, land tenure reform, public investment in research and infrastructure, and targeted subsidies for smallholder farmers [45]. Moreover, inclusive policy-making processes engaging farmers, youth, civil society, and the private sector ensure local relevance and ownership. Decentralized extension systems, e-voucher schemes, and public procurement from smallholders can reinforce institutional reach and market integration [27, 33,]. Regulatory support for innovations comparable with digital finance, e-commerce platforms, and smart insurance models is also essential. Ultimately, proactive, accountable, and well-resourced institutions are catalysts for sustainable growth, bridging gaps between innovation and impact across SSA's agricultural landscapes.

APPLICATIONS OF DATA-DRIVEN INNOVATION

Data-driven innovation is revolutionizing agriculture by integrating analytics, digital tools, and real-time insights into decision-making processes, enabling more efficient, sustainable, and productive farming systems. In sub-Saharan Africa (SSA), the application of such innovation is progressively transforming the sector, although the pace varies across regions.

One core application is predictive analytics, as indicated by Tsouros *et al.* [39] and the FAO [45], which uses big data from weather patterns, soil sensors, and historical yield records to forecast crop performance and climatic risk. This supports farmers in optimizing planting schedules, irrigation, and harvesting, thereby minimizing losses. Early warning systems that use satellite imagery and artificial intelligence (AI) are also increasingly applied to predict droughts, pest outbreaks, and floods, enabling proactive response rather than reactive crisis management [48].



According to AgroCenta [49] and FAO [50], digital financial services leverage data to assess farmers' creditworthiness on the basis of mobile transaction histories or production data. This increases access to credit, insurance and savings tools for smallholder farmers previously excluded from formal banking. For example, platforms such as FarmDrive and Tulaa in Kenya use alternative data points to offer credit scoring and input loans. Supply chain transparency is improved through blockchain and QR-coded tracking systems that collect data from the farm to the dining table [51]. This enhances traceability, reduces fraud, and builds consumer trust, especially for export markets that require strict compliance standards. It also improves inventory and logistics efficiency across agro-value chains.

At the farm level, there are smart farming technologies that utilize IoT-enabled sensors to gather granular data on soil moisture, pH, and nutrient levels, allowing for precise input applications [37]. This conserves resources and improves yields. Coupled with data dashboards, these tools help large- and small-scale farmers make real-time agronomic decisions on the basis of actionable insights. Data are also being applied in agricultural extension services through mobile apps, radio-based platforms, and AI chatbots that provide tailored advice on pest management, fertilization, and marketing. PlantVillage [47] reported that digital advisory services such as PlantVillage Nuru and Hello Tractor bridge the extension gap, especially in regions where physical outreach is limited. These tools are multilingual and often tailored to local crops and farming practices.

In agricultural research and development, open-access datasets enable scientists and policymakers to identify productivity trends, assess varietal performance under different conditions, and model policy impacts [52]. Data from field trials, household surveys, and national censuses are being harmonized to inform evidence-based policymaking, reducing inefficiencies in public investment and development aid targeting. Moreover, climate-smart agriculture heavily depends on data-driven solutions to map carbon footprints, simulate climate scenarios, and monitor emissions reduction from agricultural interventions. These data applications attract climate financing from global funds and promote sustainable land management.

As revealed by The Technical Centre for Agricultural and Rural Cooperation (CTA) [53], another emerging application is in market intelligence, where data aggregators collect and analyse real-time commodity prices, buyer demand, and transportation costs. Farmers and cooperatives use this information to plan harvests, negotiate fair prices, and avoid gluts or shortages. Digital marketplaces such as AgroMall and M-Farm empower producers by reducing information asymmetry [54]. Policy monitoring and evaluation are increasingly data driven [50]. Governments use integrated information systems to track subsidy distributions, assess food security indicators,



and monitor progress toward national and continental agricultural targets such as the Comprehensive Africa Agriculture Development Programme (CAADP) commitments.

In summary, data-driven innovation in agriculture is not limited to enhancing productivity; it redefines the entire agricultural ecosystem from financing and logistics to policy design and climate resilience. For the SSA to benefit fully, scaling up infrastructure, digital literacy, and institutional capacity remains vital.

DATA SOURCES IN AGRICULTURE

Data constitute the foundation of modern and resilient agriculture. In sub-Saharan Africa, leveraging diverse and reliable data sources is critical for improving productivity, addressing food insecurity, and adapting to climate change. The range of data sources available today enables evidence-based decision-making across the agricultural value chain. The major types of data sources and how they are applied are as follows:

Remote Sensing Technology

Remote sensing involves collecting data about the Earth's surface via satellites, drones, and aircraft. In agriculture, this technology is used to monitor crop health, soil moisture, land cover and weather events [50]. Satellite imagery helps track vegetation indices such as the normalized difference vegetation index (NDVI), which provides insights into crop vigour and potential yield estimates [45]. In SSA, tools such as SERVIR Africa and NASA Harvest support governments and farmers by providing early warnings of drought and flood, enabling adaptive response and disaster risk mitigation [55, 56]. Drone-based imaging is also emerging, offering ultrahigh-resolution data for farm-level analysis.

Internet of Things (IoT) Sensors

IoT-enabled sensors embedded in field or farm equipment collect continuous, real-time data on soil temperature, moisture levels, humidity and nutrient composition [46, 50]. These devices help optimize irrigation, fertilization and pest control [46]. For example, moisture sensors can trigger irrigation systems only when needed, conserving water. In SSA, pilot initiatives in Kenya, South Africa, and Nigeria are demonstrating the feasibility of low-cost sensor deployment even in resource-constrained settings. When integrated into mobile platforms, these data support smallholder farmers in on-the-go decision-making.

Weather and Climate Data

According to the FAO [45] and Weather Impact [57], access to timely and localized weather data is very important for agricultural planning. Data from meteorological stations, weather satellites, and climate models provide forecasts of rainfall,



temperature, wind speed, and seasonal patterns. This information assists in determining optimal planting and harvesting times to manage the risk of weather-induced crop failure [39, 50]. Services such as Where and Weather Impact provide location-specific forecasts for farmers in SSA [52, 57]. Some agritech startups also deliver SMS-based weather updates in vernacular languages, thus enhancing last-mile access.

Farm Management Software and Digital Platforms

Gebbers and Adamchuk [52] reported that digital farm management systems collect data on input use, field operations, labour, costs and yields. These platforms help track progress, analyse profitability, and ensure compliance with standards, especially for export certification. As indicated by e-Farmers [58], tools such as eFarmers in SSA allow farmers to record day-to-day activities, monitor farm performance, and access credit and insurance services. For cooperatives and agribusinesses, aggregated data enable better planning, coordination, and value chain integration.

Market and Price Data

The market data include farmgate, wholesale and retail prices, demand forecasts, transportation costs and buyer trends. Access to these data helps farmers determine what to grow, when to sell, and where to market their produce. According to M-Farm [49, 59], platforms such as AgroCenta and M-Farm collect and disseminate real-time price data to farmers via mobile apps and SMS. Some platforms integrate with e-commerce systems, allowing smallholders to transact directly with buyers and processors and reducing exploitation by middlemen.

National Agricultural Surveys and Census Data

Government agencies and national statistics offices conduct periodic agricultural censuses, household surveys, and production assessments. These datasets provide macrolevel insights into land use, input usage, crop output, and food security indicators. For example, in SSA, the African Union Commission [33] and Food and Agriculture Organisation [45] revealed that data from initiatives such as the Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA) and CAADP Biennial Reviews inform national planning, policy formulation, and investment strategies. However, gaps in frequency, accuracy and accessibility remain a challenge.

Crowdsourced and Community data

A study conducted by Mbwana *et al.* [60] revealed that some platforms rely on participatory data collection, where farmers and extension agents submit observations on crop conditions, pest outbreaks, or rainfall manually or through mobile devices. These grassroots data are valuable for mapping real-time threats



and mobilizing quick responses. For example, PlantVillage Nuru uses farmer-contributed images and inputs to detect diseases in cassava and maize across West Africa and East Africa [47]. The integration of multiple data sources enhances precision, inclusivity and sustainability in agriculture. However, for sub-Saharan Africa (SSA) to harness the full potential of these resources, the subregion requires investment in data infrastructure, harmonization standards, and institutional capacity. Strengthening data ecosystems will not only improve farm-level productivity but also support national food systems and regional development agendas.

BENEFITS OF DATA-DRIVEN INNOVATION IN AGRICULTURE

Data-driven innovation provides transformative benefits across the agricultural value chain, particularly in SSA, where challenges such as erratic weather, low productivity and limited access to markets persist [45, 57]. The integration of data enables precision agriculture, which allows farmers to make informed decisions on the basis of real-time and location-specific information. This leads to optimized use of inputs such as water, fertilizers, and pesticides, resulting in cost savings, improved yields and reduced environmental harm.

One of the most significant benefits is the enhancement of risk management. Access to timely weather forecasts, early warning systems and predictive analytics helps farmers prepare for climate variability, pests and disease outbreaks [47, 52]. This reduces crop losses and promotes resilience among smallholder farmers. Similarly, data from soil sensors and satellite imagery allow for targeted interventions that prevent overuse of natural resources and degradation of land. Market efficiency is also improved through data-driven platforms that connect producers directly to buyers, provide real-time pricing information, and facilitate digital payments. This increases bargaining power, reduces transaction costs, and eliminates exploitative middlemen.

Thus, data-enabled innovations foster inclusivity by expanding access to advisory services through mobile technology, particularly for women, youth, and remote communities. This democratization of information contributes to bridging inequality gaps in agriculture and accelerating the transition toward sustainable and resilient food systems.

CHALLENGES OF APPLYING DATA-DRIVEN INNOVATION IN AGRICULTURE

Despite its transformative potential, the adoption of data-driven innovation in agriculture faces several complex and interconnected challenges across sub-Saharan Africa. A major barrier is the high cost of technological infrastructure. Most smallholder farmers operate with limited financial resources, making it difficult to



afford IoT sensors, drones, software subscriptions, or precision machinery [37, 50]. This technological divide results in an unequal distribution of innovation benefits, further marginalizing already vulnerable groups.

Another significant constraint is digital illiteracy. Many rural farmers lack the technical knowledge required to operate data-enabled tools or interpret complex analytical outputs [18, 50]. Training and capacity-building efforts are often insufficient or poorly targeted, resulting in the underutilization of available platforms. Language barriers and low general education levels also limit engagement with mobile-based applications and digital dashboards. The problem of connectivity is a recurrent challenge in many rural and remote farming areas. Weak broadband infrastructure, irregular electricity supply, and a lack of mobile network coverage hinder real-time data collection and sharing [18, 53]. Without reliable digital infrastructure, the utility of advanced agricultural technologies is drastically reduced, slowing scalability and impact. Concerns around data privacy, ownership, and governance are also growing. Farmers may be reluctant to share personal or production-related information because of fears of misuse, exploitation by private companies, or a lack of clear legal protection [37,53]. This limits the data ecosystem's richness and creates mistrust among stakeholders.

Moreover, interoperability between digital systems remains a technical challenge. Incompatible platforms, fragmented databases, and proprietary standards reduce the ability to aggregate and analyse agricultural data holistically. This results in inefficiencies and missed opportunities for cross-sector insights.

PROSPECTS OF DATA-DRIVEN INNOVATIONS FOR AGRICULTURAL TRANSFORMATION

The future of data-driven innovation in agriculture is poised for significant advancements that promise to revolutionize farming practices, especially in SSA [18, 59]. Emerging technologies such as artificial intelligence (AI) and machine learning are expected to play crucial roles in analysing complex agricultural datasets [50, 53]. These tools will enable farmers and policymakers to identify patterns in crop growth, pest outbreaks, and climate variability with unprecedented accuracy, allowing for more precise and timely interventions. The adoption of blockchain technology is also gaining momentum, offering solutions for transparent and secure data sharing across the agricultural value chain. Blockchain can improve traceability from the farm to the retail store and the dining table, ensuring the authenticity of organic or fair-trade labels and facilitating secure transactions, thereby building trust among farmers, buyers, and consumers. This level of transparency can increase market access for smallholder farmers and improve food safety standards [22].



With the rollout of 5G networks and edge computing, real-time field analytics will become more feasible even in remote areas. This will enhance the responsiveness of smart farming equipment and IoT sensors, allowing instant decision-making on the basis of current field conditions. These developments will contribute to more efficient resource use and better climate adaptation strategies [37, 53]. The integration of climate models with agricultural data will be essential for building adaptive farming systems capable of withstanding extreme weather events [39, 50]. Predictive analytics can help forecast droughts or floods months in advance, enabling farmers to modify planting schedules or select resilient crop varieties.

Furthermore, the rise of digital platforms and mobile apps will continue to expand access to advisory services, credit facilities, and market information, particularly benefiting women and youth. These platforms will increasingly incorporate localized knowledge and participatory approaches, ensuring relevance and usability. Policy frameworks are expected to evolve, emphasizing data governance, interoperability and capacity building. Public–private partnerships are critical for mobilizing investments, scaling innovations and ensuring inclusivity.

Overall, data-driven agriculture in sub-Saharan Africa is moving towards a future marked by greater precision, sustainability and equity, fostering resilient food systems that can meet growing demands.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

There is no doubt that Africa's agricultural sector faces significant challenges, strategic investments, policy reforms, and inclusive practices that offer pathways to transformation. However, by leveraging its resources and human capital (particularly youth capital), Africa has the capacity to achieve food security and sustainable economic growth. The agricultural sector in sub-Saharan Africa (SSA) stands at a critical crossroad. Despite its vast natural resources and potential, Africa continues to face systemic challenges, including low productivity, climate vulnerability, inadequate infrastructure, and chronic food and nutrition insecurity. These challenges are further aggravated by climate change, soil degradation, and constrained access to markets.

This paper has demonstrated that data-driven innovation offers a compelling and transformative pathway to revitalizing agriculture across the continent. The integration of advanced technologies ranging from precision agriculture and remote sensing to AI-based analytics and digital platforms reveals opportunities to increase efficiency, enhance decision-making, and improve resilience at both the farm and system levels. These technologies, when underpinned by robust data sources and inclusive access, have the potential to revolutionize farming practices, reduce



environmental impacts, and create economic opportunities, particularly for vulnerable women and young people.

Regardless, significant barriers such as high costs of technology adoption, digital illiteracy, weak rural connectivity, and fragmented data governance frameworks portend real risks to widespread implementation. Therefore, strategic investments in infrastructure, capacity building, and enabling policy environments are urgently needed. Collaboration among governments, private sector players, research institutions, and farming communities will be crucial to closing the digital divide and ensuring equitable access to innovation. The future of agriculture in SSA hinges not only on the adoption of smart technologies but also on how effectively these innovations are integrated into local solutions. By leveraging data intelligently, promoting sustainability, and prioritizing inclusive growth, Africa can build resilient food systems capable of withstanding future shocks, ensuring food and nutrition security for unborn generations, and accelerating progress toward achieving the Sustainable Development Goals (SDGs).

To strengthen agricultural productivity and resilience in SSA, the following recommendations are worth considering. Governments should prioritize investments in rural digital infrastructure, including internet connectivity and electricity, to enable technology access in underserved remote agricultural communities. Strengthening national agricultural statistical systems and establishing centralized data repositories can ensure the availability of accurate and timely data for informed decision-making. Policymakers should formulate supportive regulatory frameworks to safeguard data privacy, encourage Public Private Partnerships (PPPs), and ensure equitable access to digital technologies. Subsidizing smart farming tools and platforms for smallholder farmers will enhance their ability to adopt innovation without facing prohibitive costs. Promoting national policies that prioritize precision agriculture, ICTs, and climate-smart farming is also essential. Also, encourage the development and use of open-source farm management software tailored to local conditions will promote affordability and accessibility. Expanding training programs in digital literacy and agri-tech for new and emerging farmers, extension workers, and agribusiness professionals is critical to capacity building. Governments and research institutions must invest in local innovation hubs that foster data science applications in agriculture. Strengthening meteorological services to offer reliable and localized agro-weather information will enhance resilience and planning. The integration of digital payment systems into agricultural value chains can support transparency and financial inclusion. Again, governments should include agriculture-specific modules in vocational and higher education to prepare a skilled workforce for national development. National centres of excellence in agricultural data science and artificial intelligence (AI) should be established to localize technological solutions. Tax



rebates must be given to private companies investing in agricultural data systems, rural technology, or farm-to-market platforms. Indigenous knowledge should be incorporated alongside digital innovations to ground solutions in local contexts. Additionally, low-cost sensor technologies and climate-smart innovations should be widely deployed to improve monitoring and productivity while addressing climate risks.



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