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Digital innovations in semi-arid agriculture: A case study of precision farming in Opsoek ladismith, Karoo

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ABSTRACT

Agricultural production in semi-arid regions such as Opsoek, Ladismith Karoo faces numerous challenges, including water scarcity, low soil fertility and unpredictable weather patterns. Digital innovations, particularly precision farming and mobile extension systems have proven to be important tools in overcoming these challenges and promoting sustainable agricultural practices. This case study examines the adoption and impact of precision farming technologies and mobile support services among farmers in Opsoek. The research combines field observations, interviews with local farmers and analysis of data on the use of mobile extension services. The results show that precision agriculture tools, such as soil moisture sensors, GPS-based field mapping and automatic irrigation systems, have significantly improved resource management and crop yields. In addition, mobile extension services improved farmers' access to timely information on weather forecasts, pest control and best farming practices, thereby strengthening decision-making processes and reducing production risks. Despite the obvious benefits, the study notes that barriers remain, such as limited digital literacy, high costs of technological inputs and inadequate mobile network coverage, which hinder wider adoption among smallholder farmers. The study concludes that targeted digital literacy training, government support for affordable technology access and improved rural network infrastructure are essential to fully realize the potential of digital innovation in semi-arid agriculture. This study contributes to the growing body of literature highlighting the transformative role of digital technologies in improving agricultural productivity and resilience in water-scarce areas and provides practical insights for policy makers, development practitioners and agricultural technology innovators.

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Introduction

Agriculture remains the backbone of many rural economies around the world, particularly in semi-arid regions such as Opsoek in the Ladismith Karoo, where farming is both a vital livelihood and a constant battle against adverse environmental conditions. These regions face growing challenges such as drought, land degradation and unpredictable climate patterns (Zain et al., 2024). In response, digital agriculture is rapidly emerging as a key driver of change within the broader agribusiness ecosystem by reshaping technology markets, boosting local economies and promoting agricultural connectivity. The integration of digital tools not only increases farm efficiency but also contributes to sustainable rural development by enabling data-driven decisions, improving market access and promoting environmentally friendly practises.

This study focuses on the key precision agriculture technologies used in Opsoek, such as soil moisture sensors, automated irrigation systems and the locally customised AgriSuiteSA platform, which together enable site-specific crop and water management. These innovations are designed to optimise resource use, increase yields and mitigate the effects of climate variability (Senoo et al., 2024). In addition to these technologies, mobile agricultural extension services play a critical role in providing real-time updates on weather forecasts, pest outbreaks, market prices and agronomic advice, enabling farmers to make informed and timely decisions (Farooqui et al., 2024).

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Despite global enthusiasm, uptake among smallholder farmers remains limited due to high costs, technical barriers and low digital literacy (Gardezi et al., 2024). In sub-Saharan Africa, mobile communication has improved interaction between farmers and extension workers, but limited infrastructure continues to limit its impact (Polwaththa et al., 2024). Few studies have systematically investigated the combined impact of these technologies in marginalised, water-scarce areas such as Opsoek. Existing research often focuses on either large-scale precision agriculture or isolated mobile solutions, ignoring the complexities of smallholder contexts (Nyéki & Neményi, 2022).

This case study fills this gap by examining the adoption, outcomes and barriers of digital farming in Opsoek. It examines how precision tools and mobile platforms influence farmers' resource management, decision-making and climate resilience. The findings are intended to help policy makers, development agencies and technology providers in the search for inclusive digital transformation strategies for semi-arid and rural communities. Ultimately, this study contributes to a broader discourse on how digital innovations can bridge productivity gaps and support climate-smart agriculture in vulnerable regions.

Literature Review

Precision Agriculture in Semi-Arid Regions

Precision agriculture (PA) refers to the use of advanced technologies such as global positioning systems (GPS), geographic information systems (GIS), remote sensing and soil sensors to optimize agricultural practices (Videgain et al.,2024). The fundamental goal of precision agriculture is to manage field variability and increase crop yields while minimizing environmental impacts (El-Gindy et al.,2024).

In semi-arid regions, where water scarcity and soil variability are a major challenge, PA technologies have shown significant potential (Galal & Soliman, 2024). Soil moisture sensors, automatic irrigation systems and variable rate application technologies have enabled farmers to use inputs more precisely and thus conserve limited resources (Kganyago et al., 2024). Studies conducted in Australia and parts of the United States, for example, show that PA has improved water use efficiency in semi-arid areas by up to 30 % (Kganyago et al., 2024; Galal & Soliman, 2024).

Despite these benefits, uptake among smallholder farmers in developing countries remains relatively low (Alharbi et al., 2024). High initial investment costs, lack of technical skills and limited access to infrastructure are the main barriers (Duan et al.,2024). Furthermore, Guebsi and El Wai (2025) emphasize that context-specific adaptation of PA tools is crucial in semi-arid agricultural systems due to their unique socio-ecological dynamics.

Mobile-based Agricultural Advisory Services

Mobile-based agricultural extension services have proven to be an effective means of providing timely information to farmers, especially in remote and underserved areas (Adla et al.,2025). These services include mobile applications, SMS-based notifications, and interactive voice response systems that provide data on weather forecasts, pest outbreaks, market prices, and agricultural best practices (Mallick et al.,2025).

Research in sub-Saharan Africa has found that cell phones significantly improve farmers' access to market information and technical advice, contributing to better crop management and higher incomes (Mukherjee et al.,2025; Muromba, 2025). In Kenya, for example, mobile phone-based platforms such as iCow and M-Farm have successfully bridged information gaps among smallholder farmers (Muromba, 2025).

However, barriers such as digital literacy, language limitations and uneven mobile network coverage continue to hinder the full utilization of these platforms (Fernando et al.,2025). Furthermore, Kandel et al. (2025) note that while the availability of information has improved, its effectiveness depends on the relevance, timeliness and credibility of the messages conveyed.

Synergy Effects between Precision Agriculture and Mobile Consulting

The integration of PA technologies and mobile extension services creates a synergistic effect by combining real-time field data with actionable advice, improving farmers' decision-making capabilities (Tadele et al., 2025). Mobile platforms can facilitate the interpretation of complex sensor data and make PA tools accessible to farmers with limited technical expertise (Jaya Krishna et al., 2025). According to Michelson (2025), in Ghana, precision mapping services combined with mobile extension support led to significant yield increases for maize farmers. This underscores the potential of combining technological and informational interventions to address several constraints in semi-arid agriculture. Nevertheless, implementation requires a comprehensive approach that includes investment in infrastructure, capacity building and the development of local technologies (Fraval et al., 2019). Without these supportive frameworks, the risk of digital exclusion of resource-poor farmers remains high (Tavenner et al., 2019).

Barriers to Adoption and Socio-Economic Factors

Socio-economic factors play a crucial role in the adoption of technology. Studies have shown that younger, better educated farmers are more willing to adopt precision farming and mobile technologies (Luna-delRisco et al.,2025). Conversely, older farmers with less formal education often find it difficult to engage with digital platforms (Pandeya, Gyawali & Upadhaya, 2025). Gender

inequalities also persist. Women farmers tend to have less access to cell phones and extension services, which exacerbates their marginalization in digital agriculture initiatives (Pandeya et al., 2025). Addressing these inequalities through gender-specific interventions is crucial to realizing an inclusive agricultural transformation. Furthermore, trust in technology providers and advisors has a significant impact on adoption rates. Farmers are more inclined to use digital tools if they perceive the information as credible and useful (Devadas & Ayyappan, 2025).

Digital Agriculture in South Africa

South Africa is a unique case for the adoption of digital agriculture as it has a dualistic agricultural structure with large commercial farms and smallholder farmers (Prause, 2025). Commercial farms have largely opted for precision technologies due to economies of scale and better access to capital (Parkhomchuk et al.,2025). In contrast, smallholder farmers in regions such as the ladismith in Karoo lag behind due to limited financial resources, poor infrastructure and inadequate support systems (Woomer et al., 2025). Initiatives such as the Department of Agriculture's e-voucher program, which aims to provide digital support to smallholder farmers, have had mixed results due to implementation issues (Department of Agriculture, Forestry and Fisheries [DAFF], 2018). Mobile extension services, while promising, face significant hurdles in rural South Africa, particularly in terms of network reliability and the high cost of mobile data (Tinarwo et al., 2025). Nonetheless, pilot programs have shown that digital tools, with appropriate support, can significantly increase agricultural productivity and resilience in marginalized communities (Ngulube, 2025). However, to achieve meaningful and equitable impact, barriers of cost, ability, gender, infrastructure and institutional support must be addressed. In the context of Opsoek, Ladismith Karoo, the successful integration of digital innovation will depend on localized strategies that prioritize inclusivity, relevance and sustainability.

Local Context: South African Initiatives and Challenges in the Field of Digital Agriculture

The South African agricultural sector is currently undergoing a digital transformation driven by the need to improve productivity, sustainability and resilience in the face of environmental, economic and socio-political challenges. In response, several national and provincial initiatives have been launched to promote the adoption of digital agricultural technologies in various farming systems, including in semi-arid regions such as the Ladismith Karoo. At a national level, the Department of Agriculture, Land Reform and Rural Development (DALRRD) has introduced the Digital Agriculture Strategy for South Africa (2020), a comprehensive roadmap that promotes the integration of new technologies — such as remote sensing, IoT, AI and blockchain — into agricultural practice. The strategy emphasizes inclusivity by targeting smallholder farmers, particularly in underserved rural areas, through digital training, infrastructure investment and partnerships with technology providers.

At provincial level, the Western Cape Department of Agriculture (WCDoA) has introduced several pioneering programmes tailored to the region’s arid and climatically volatile landscape. Chief among these is the Smart Agri Plan (2016), a climate change response framework that champions climate-adapted agricultural technologies, including precision irrigation systems, climate data platforms and GIS-based land use planning. This plan has been particularly influential in the Central Karoo and Overberg districts, where it supports farmers in adapting to water scarcity and extreme weather variability. Complementing Smart Agri is the Cape Farm Mapper initiative, which provides freely accessible geospatial data to support decision making on land use, soil type assessment and climate risk mapping. It is widely used in the Karoo to support farmers in optimising their land resources

In addition, research by the Agricultural Research Council (ARC) has emphasised the need for more localised innovation ecosystems in which universities, agricultural technologies, government agencies and farmers' cooperatives work together to develop technologies suitable for smallholder and semi-arid agriculture.

In the specific context of Opsoek in Ladismith, many of these challenges are compounded by the remoteness of the area and the socio-economic vulnerability of the farming communities. However, initiatives such as AgriSuiteSA, a modular decision support tool developed through partnerships between local developers and provincial stakeholders, are showing promising results in bridging the gap between digital innovation and rural practice. By providing customised advice on irrigation scheduling, pest control and soil management, such tools show how digital agriculture can be scaled to low-resource settings.

The South African example thus illustrates both the potential and the complexity of digital transformation in agriculture. For communities like Opsoek, success will depend not only on the adoption of technology, but also on building inclusive support systems, policies and knowledge networks that ensure rural farmers are able to benefit from these innovations.

Research and Methodology

Research Design

This study uses a qualitative case study design to explore the role and impact of precision agriculture and mobile extension in semi-arid agricultural contexts, focusing on the farming community of Opsoek in the Ladismith Karoo. A case study approach is ideal for gaining a deep understanding of contemporary phenomena in a real-world setting where the boundaries between the phenomenon and the context are not clearly recognizable (Yin, 2014; Tobita, 2025). By focusing on a single geographical area with unique socio-economic and environmental characteristics, the study provides rich, contextualized insights into the patterns and challenges of digital innovation adoption.

Study Area

The study was conducted in Opsoek, an agricultural settlement in the Ladismith district in the Western Cape Karoo region, South Africa. The area is characterized by semi-arid climatic conditions, low annual rainfall (usually less than 300 mm), high evapotranspiration rates and low soil fertility. These conditions require efficient resource management and make the region a suitable environment to study the importance and impact of precision agriculture and mobile extension technologies.

Sampling and Participants

A purposive sampling strategy was used for the study to select participants who had been exposed to either precision agriculture technologies, mobile agricultural extension services or both. Twenty (20) farmers were selected consisting of:

i. 10 smallholder farmers (farming less than 5 hectares)
ii. 5 medium scale farmers (with an area of 5–20 hectares)
iii. 5 commercial farmers (with an area of more than 20 hectares)

In addition, two agricultural consultants and a technology service provider operating in the region were interviewed to obtain additional information. Participants were selected based on their experience with at least one form of digital agriculture within the last three years. This criterion ensured that participants could meaningfully reflect on both the benefits and challenges associated with digital tools.

Methods of Data Collection

Semi-structured interviews served as the primary method of data collection. An interview guide was developed to cover the most important topics:

i. Awareness and use of precision agriculture tools
ii. Interaction with mobile extension platforms
iii. Perceived benefits and challenges
iv. Socio-economic factors that influence acceptance
v. Recommendations for improving digital services

The interviews were conducted face-to-face, lasted around 45–60 minutes each and were recorded with the consent of the participants. Field observations were also conducted to verify the presence and use of technologies (e.g. drip irrigation systems, soil sensors, use of mobile apps) on the farms. Detailed field notes were kept. In addition, secondary data was collected from existing reports and analysis of the mobile extension platform to quantitatively underpin usage patterns (e.g. frequency of SMS queries and application downloads).

3.5 Data analysis

The data were transcribed and analysed using thematic analysis according to Braun and Clarke's (2006) six-step procedure:

i. Familiarization with the data
ii. Coding
iii. Search for topics
iv. Review of topics
v. Defining and naming topics
vi. Writing the report

The topics that arose included:

i. Drivers for technology adoption (e.g. managing water scarcity, profit incentives)
ii. Barriers to adoption (e.g. costs, digital literacy issues)
iii. Impact on productivity and resilience
iv. Role of advice officers and mobile platforms

NVivo 12 software was used to systematically manage and code the qualitative data to increase the reliability and transparency of the analysis.

Validity and Reliability

To ensure credibility and trustworthiness, triangulation was used by combining interview data, field observations and secondary data sources. Preliminary results were shared with five participants to check the accuracy and representation of views (Luong, 2025). Transferability was ensured through extensive, detailed descriptions of the research context so that the reader can assess the transferability of the results to similar situations. Reliability and confirmability were supported by keeping a log of the research procedures, including the recorded interviews, field notes, coding frames, and data analysis decisions.

Ethical Considerations

The study complied with ethical research practices. Ethical approval was obtained from the relevant review board. All participants were informed of the purpose of the study, their voluntary participation and the confidentiality of their responses. Written informed consent was obtained prior to the start of data collection. Pseudonyms were used in all protocols and reports to protect the identity of the participants. Data was stored securely on encrypted devices that could only be accessed by the research team.

Findings and Discussions

Overview of the Results

Twenty participants were selected for this study, including ten smallholder-scale farmers, five medium-scale farmers and five commercial farmers from Opsoek, Ladismith Karoo. The age ranged from 28 to 67 years, with an average age of 46 years. Male farmers made up 70% of the sample, while female farmers made up the remaining 30%. Educational backgrounds varied widely: 40% had completed secondary school, 30% had only attended elementary school and 30% had some form of post-secondary education, often an agricultural diploma.

In terms of digital access, 100% of participants own at least one cell phone. However, only 55% own smartphones capable of running mobile agricultural applications. Feature phones with SMS capability were more common among smallholder farmers. Internet access was sporadic, especially among those who lived further away from the main town of Ladismith, as network coverage is limited in the mountainous Karoo.

Precision farming tools varied according to farm size. All five commercial farmers had invested in GPS-based field mapping, automatic drip irrigation and soil moisture monitoring systems. In contrast, only three of the ten smallholder farmers had access to some form of precision agriculture tools, primarily low-cost soil moisture sensors provided as part of a government pilot project.

Mobile extension platforms used included SMS-based extension services, WhatsApp farmer groups and mobile apps such as AgriSuiteSA. Around 65% of participants said they had used at least one form of mobile advice in the past year, with higher usage among younger and more educated farmers. Initial interviews revealed a generally positive attitude towards digital tools. However, several respondents, especially smallholders, expressed concerns about the complexity of the technologies and affordability. One farmer commented: "These new devices are good, but they are expensive and complicated if you don't know how to use them." (Smallholder, Opsoek).

Discussions

Adoption of technologies for precision agriculture in Opsoek

Field data from Opsoek, Ladismith, showed that the use of precision agriculture (PA) technologies varied widely across farm sizes. All five commercial farmers used technologies such as GPS field mapping, automatic drip irrigation systems and simple remote soil moisture sensors. This trend is consistent with the findings of Videgain et al. (2024), who demonstrated that differentiated seeding and precision irrigation have become commonplace among larger, better-equipped farmers working in semi-arid conditions. However, smallholder farmers in Opsoek were less accepting. Only three out of ten smallholder farmers used simple soil moisture probes and manual GPS tracking for field mapping, often supported by government pilot projects (DAFF, 2018). This pattern mirrors the findings of Pandeya et al. (2025), who found that small farmers in Kentucky were similarly lagging behind in adopting costly precision technologies due to capital and knowledge barriers.

Interestingly, farmers in Opsoek noted that they were more receptive to low-cost innovations that directly addressed their water management problems. This supports Alharbi et al. (2024), who emphasize that technologies that improve water use efficiency are adopted faster in arid and semi-arid regions. Nanotechnology-enhanced soil moisture sensors are being researched worldwide (Zain et al., 2024), but have not been observed by farmers in Opsoek, mainly due to lack of market access and cost constraints. The potential of nanotechnology remains high, but its diffusion in practice is still limited to advanced agricultural economies.

Use of mobile advisory services

Mobile agricultural extension platforms played a central role in Opsoek, especially for farmers who do not have regular access to government extension officers. 70% of participants used SMS-based services for weather information, pest warnings and market prices. This is in line with the findings of Muromba (2025) and Mukherjee et al. (2025), who both emphasize the transformative role of mobile services for smallholder farmers in sub-Saharan Africa. However, the use of mobile apps (e.g. AgriSuiteSA, WhatsApp farmer groups) was more prevalent among medium and commercial farmers, indicating a digital divide depending on education and income level. Fernando et al. (2025) emphasized that farmers' ability to benefit from such services is critically dependent on how proficient they are with cell phones — a trend clearly visible among older farmers in Opsoek who rely solely on voice calls or simple SMS notifications. The participatory development of mobile services advocated by Adla et al. (2025) was absent in Opsoek, leading to complaints that some notices were "too general" or "not local enough." This confirms the need for behavioural adaptation of mobile advice.

Observed benefits of digital innovations

Farmers using both precision farming and mobile advice reported notable benefits:

i. Water use efficiency improved by 25–35%
ii. Crop yields increased by 15–22% (especially for drought-tolerant maize and beans)
iii. Reduction in input costs (fertilizers, pesticides) by optimizing application rates

These results are comparable to the water saving successes achieved in Tunisia using drones in precision farming (Guebsi & El Wai, 2025) and in arid areas of the USA using remote sensing (Mehedi et al., 2024).

Farmers in Opsoek who participated in smart irrigation pilot programs achieved similar results to Galal and Soliman (2024), where drip irrigation combined with moisture measurements significantly extended the growing season under drought stress.

A commercial farmer in Opsoek noted: "Since I have weekly soil reports on my phone, I only irrigate when necessary. That saves me thousands in water costs." This finding echoes the conclusions of Getahun et al. (2024) regarding the role of real-time monitoring in sustainable agricultural practices.

Challenges and obstacles to implementation

Despite the recognizable advantages, there are still considerable obstacles to its introduction:

i. Cost has been a major barrier, as also documented by Pandeya et al. (2025) and Luna-delRisco et al. (2025).
ii. The lack of digital literacy, especially among older farmers, echoes the concerns expressed by Muromba (2025) and Mallick et al. (2025).
iii. The unreliability of the network, particularly during the peak agricultural season, was a frequently cited problem, which echoes Ngulube (2025) on the infrastructural weaknesses in tropical African farming areas.
iv. Limited localized content led to mistrust in extension platforms, like the problems noted by Mukherjee et al. (2025).

In addition, structural gender differences limited women farmers' access to mobile extension services — a challenge also highlighted by Quisumbing et al. (2015) in their studies on gender and agriculture.

Influence of socio-economic factors

The socio-economic profiling revealed the following:

i. Farmers with higher education (secondary or college degree) were more likely to use both precision farming tools and mobile platforms.
ii. Younger farmers (under 40) were more likely to adopt technologies than older farmers, which is consistent with Devadas & Ayyappan (2025).
iii. Farmers with off-farm income were more willing to invest in digital upgrades, consistent with the findings of Luna-delRisco et al. (2025) in Colombia.
iv. Socio-economic conditions were therefore crucial, supporting the argument of Parkhomchuk et al. (2025) that digital agriculture is not only about the availability of technology, but also about a broader environment.

The role of technology, AI, IoT and remote sensing

While basic sensors and SMS services dominated in Opsoek, there were early signs of a growing interest in:

i. AI-driven advisory platforms (although not yet widely used locally) supported by global trends documented by Jaya Krishna et al. (2025).
ii. Use of remote sensing and satellite imagery for field mapping on commercial farms, in line with technological trends described by Duan et al. (2024) and Kganyago et al. (2024).
iii. Interest in drones among commercial farmers, although only two of them had experimented with drone-based mapping and cited costs as the main barrier.
iv. The global development towards Agriculture 4.0 technologies outlined by El-Gindy et al. (2024) is still at an early stage in Opsoek but offers future opportunities.

These results confirm the more general conclusions about the transformation of African agriculture formulated by Woomer et al. (2025) and Tinarwo & Erasmus (2025). Furthermore, the results underscore the assertion by Wijk et al. (2018) that increasing smallholder farmer productivity through technology requires tailored, context-specific interventions rather than one-size-fits-all models.

Conclusion

This study investigated the adoption and impact of precision farming and mobile extension in the semi-arid farming community of Opsoek, Ladismith Karoo. The results confirm that while digital innovations offer significant opportunities to improve agricultural productivity, water use efficiency and resilience, uptake varies greatly by farm size and socio-economic group. Commercial farmers in Opsoek were early adopters of precision agriculture technologies such as GPS mapping, soil sensors and automated irrigation, and have seen significant benefits in optimizing yields and resources. In contrast, smallholder farmers primarily used low-cost mobile extension services but faced persistent barriers, including affordability issues, digital literacy and weak infrastructure — findings that are consistent with broader patterns documented in studies of African agricultural transformation. Despite these barriers, there is great potential for scaling up digital agriculture among smallholder farmers through targeted interventions. Key enablers include accessible mobile services, participatory technology design, localized extension content, improvements in rural connectivity, and tailored training programs.

Recommendations include:

i. Introduction of subsidized access to low-cost precision equipment for smallholder farmers.
ii. Strengthening digital literacy programs that target older and less educated farmers.
iii. Improve network infrastructure in rural areas to support mobile services.
iv. Promote gender-responsive digital strategies to ensure that women farmers benefit equally.
v. Promote public-private partnerships for the dissemination of mobile extension platforms and innovations in precision agriculture.
vi. A context-sensitive, multi-stakeholder approach is crucial to realizing the full potential of digital innovation in South Africa's semi-arid agricultural landscapes.

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