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Article

Systematic literature review on the application of precision agriculture using artificial intelligence by small-scale farmers in Africa and its societal impact

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Abstract: The economy, unemployment, and job creation of South Africa heavily depend on the growth of the agricultural sector. With a growing population of 60 million, there are approximately 4 million small-scale farmers (SSF) number, and about 36,000 commercial farmers which serve South Africa. The agricultural sector in South Africa faces challenges such as climate change, lack of access to infrastructure and training, high labour costs, limited access to modern technology, and resource constraints. Precision agriculture (PA) using AI can address many of these issues for small-scale farmers by improving access to technology, reducing production costs, enhancing skills and training, improving data management, and providing better irrigation infrastructure and transport access. However, there is a dearth of research on the application of precision agriculture using artificial intelligence (AI) by small scale farmers (SSF) in South Africa and Africa at large. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) and Bibliometric analysis guidelines were used to investigate the adoption of precision agriculture and its socio-economic implications for small-scale farmers in South Africa or the systematic literature review (SLR) compared various challenges and the use of PA and AI for small-scale farmers. The incorporation of AI-driven PA offers a significant increase in productivity and efficiency. Through a detailed systematic review of existing literature from inception to date, this study examines 182 articles synthesized from two major databases (Scopus and Web of Science). The systematic review was conducted using the machine learning tool R Studio. The study analyzed the literature review articled identified, challenges, and potential societal impact of AI-driven precision agriculture.

Keywords: algorithms; small-scale farmers (SSF); precision agriculture (PA); artificial intelligence (AI); crop management; machine learning

1. Introduction

Agriculture plays a crucial role in South Africa, significantly impacting the economy and providing numerous job opportunities. However, this sector faces various challenges, such as unpredictable weather, soil erosion, and limited resources (Charania and Li, 2020; Mizik, 2023). Precision agriculture is one of the pivotal approaches use to address these issues by using advanced technologies to boost crop yield and improve the livelihoods of small-scale farmers (Sampene et al., 2022). In recent years, the application of artificial intelligence (AI) in precision agriculture has gained significant attention. Precision agriculture is a mechanism for managing and integrating a technological system into agricultural practices for optimization purposes (Senoo et al., 2024)

The International Society for Precision Agriculture defines precision agriculture (PA) as a management strategy that gathers, processes, and analyses temporal, spatial, and individual data and combines them with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability, and sustainability of agricultural production. AI-driven precision agriculture utilizes machine learning algorithms, computer vision, and other advanced technologies to collect, analyze, and interpret data from various sources, such as soil sensors, weather stations, and satellite imagery (Kumar et al., 2022). This information is then used to make informed decisions about crop management, including irrigation, fertilization, and pest control (de Melo et al., 2023; Kumar et al., 2022). According to available data, precision agriculture involves making more "correct" decisions per unit of land per unit of time, improving the quantity and/or quality of output, improving the environment, and using inputs more efficiently. This shift focuses on the ability to make superior decisions in both time and space. Like many other regions of the world, the implementation of PA for small-scale farmers (SSF) has been geared towards meeting the demands and challenges faced by farmers to increase farm output. These limitations are numerous and diverse, and the PA technologies that have been employed, clearly reflect this diversity (Payero, 2024). Given the availability of knowledge on agricultural production limits and the development of technologies to overcome them, PA has huge potential to improve agricultural practice and production in SSF. However, compared to North America and Western Europe, SSFs in South Africa and Africa have adopted PA at a relatively low rate. While some PA has been adopted in South Africa, the extent of its implementation remains unclear (Balatsouras et al., 2023; Onyango et al., 2021).

Precision agriculture (PA) is an example of innovation in the agricultural domain, representing a model shift from traditional farming methods to data-driven, technology-enabled practices (Onyango et al., 2021). At its core, PA utilizes a diverse collection of cutting-edge technologies, with artificial intelligence (AI) playing a central role in driving its transformative potential and capability. Precision agriculture allows farmers to optimize every aspect of their operations by combining AI algorithms with advanced sensing, monitoring, and decision-making. From seed selection and irrigation management to pest control and crop-yield prediction, every stage benefits from this integration (Abioye et al., 2022). Furthermore, PA enhances crop and soil monitoring precisions, remote sensing, pest control, and yield predictions (Agrawal et al., 2023; Akansah et al., 2022; Mendoca et al., 2023; Sandiya et al., 2022). The adoption of precision agriculture has witnessed remarkable strides in large-scale commercial farming enterprises across the globe. However, it has the potential to catalyze agricultural development and empower small-scale farmers, particularly in regions like South Africa (Onyango et al., 2021). South Africa's agricultural landscape is characterized by a variety of agricultural systems, ranging from highly mechanized commercial farms to subsistence-oriented smallholder plots. The latter, comprising a significant portion of the country's rural population, often deals with an array of challenges. Some of these challenges include limited access to land, water, and markets, as well as vulnerabilities to climate change and market fluctuations (Georgopoulos et al., 2023; Gokool et al., 2023).Similarly, numerous issues confront the world's agricultural sector, such as urbanization, population increase, resource competition, climate change, and natural disasters (Pandey et al., 2022).

On the other hand, the worldwide population presents a significant challenge to the agri-food industry. One of the ways to address land shortage is to increase production efficiency. Another solution is applying precision agriculture (PA). Most farms are small-scale operations that struggle to implement precision agriculture technologies, particularly in developing nations (Mizik, 2023). Similarly, digital agriculture has emerged as a promising means of tackling the contextual difficulties faced by smallholder farmers. However, because of their undeveloped or non-existent digital ecosystems, many smallholder farmers do not have access to these digital solutions (Gumbi et al., 2023).

Precision agriculture with AI offers a beacon of hope for small-scale farmers in South Africa. With the help of AI-powered tools like satellite imagery, drones, and sophisticated algorithms, these farmers can get a clearer picture of their land, crops, and surroundings (Gokool et al., 2023). Equipped with this knowledge, farmers can make smarter choices that optimize their resources further, boost their harvests, and manage unexpected weather setbacks more effectively and efficiently. However, the path to widespread adoption of AI-driven precision agriculture among small-scale farmers in South Africa is not without its challenges (Gwagwa et al., 2021). Technical barriers, including the high cost of technology acquisition and maintenance, as well as the lack of technical expertise and digital literacy, present formidable obstacles to implementation (Sparrow et al., 2021; Tzachor et al., 2022). Socio-economic factors further complicate the adoption process, such as access to credit, land lease arrangements., and institutional support (Chougule and Mashalkar, 2022). Tzachor et al. (2022) emphasize the need for context-specific solutions that address both technological and institutional dimensions of agricultural development. The research question for the article is the investigation of systematic review literature on the precision agriculture using artificial intelligence by small scale farmers in Africa and its societal impact.

This paper investigates the subtle interplay between precision agriculture, artificial intelligence, and small-scale farming in Africa. Through a comprehensive literature review of existing literature, methodological analysis, and insights gathered from on-the-ground research, this study seeks to unravel the complexities of precision agriculture adoption and clarify its potential benefits and drawbacks. Furthermore, the paper examines the application of AI-driven precision agriculture by small-scale farmers in Africa and in turn its societal impact. A review of the existing literature followed by an analysis of the benefits and challenges of AI-driven precision agriculture. It concludes with recommendations for future research and policy interventions, providing practical guidance for policymakers, practitioners, and sponsors aiming to leverage AI-driven precision agriculture to improve the livelihoods of small-scale farmers and enhance the overall agricultural community in South Africa and beyond.

2. Literature review

The application of AI in precision agriculture has been the subject of numerous studies in recent years. A review of the existing literature reveals several key themes, including the potential benefits of AI-driven precision agriculture, the challenges associated with its implementation, and the need for further research to address these challenges. Precision agriculture and artificial intelligence have become vital components of modern agricultural practices worldwide. This section explores deeper into the intersection of these two fields, examining the adoption of precision agriculture in South Africa, its socio-economic impact, as well as the challenges and barriers faced by small-scale farmers. Similarly, the existing body of research on the application of precision agriculture and AI in the South African context provides valuable insights and a foundation for further exploration. Studies have highlighted the potential benefits of these technologies, including increased crop yields, improved resource efficiency, and enhanced resilience to climate change (Sharma et al., 2020). Additionally, researchers have examined the specific challenges faced by small-scale farmers in adopting precision agricultural tools and have proposed strategies to address these barriers. These include the development of user-friendly and affordable solutions. The literature also underscores the importance of aligning precision agriculture practices with sustainable development goals, emphasizing the need to minimize the environmental impact of agricultural activities.

2.1. Precision agriculture and artificial intelligence

Precision agriculture represents a newly emerging approach to agricultural management, which optimizes input and farming practices on a spatial and temporal basis in fields. This optimization aims to increase crop yields, minimize input costs, and reduce environmental impacts (Ly, 2021). The success of these implementations hinges on and is anchored on the integration of state-of-the-art global positioning systems, remote sensing, and AI-powered analytics. These technologies enable farmers to collect, analyse, and interpret soil properties, weather conditions, crop health, and yield variability information at very high spatial resolution (Chougule and Mashalkar, 2022; Kühl, 2021).

The vast amounts of data generated in precision agriculture can be processed and analysed using artificial intelligence, particularly machine learning algorithms. Techniques such as neural networks, support vector machines, and decision trees help to identify patterns, correlations, and anomalies within agricultural data. These insights range from predictive modelling of crop yields and pest infestations to real-time decision support for irrigation scheduling and nutrient management.

2.2. Adoption of precision agriculture in South Africa

While large-scale commercial farmers in developed countries have embraced precision agriculture, its adoption among small-scale and subsistence farmers has been limited. The major determinants of adoption are farm size, availability of resources, technical knowledge, and institutional support. Sharma et al. (2020) argue that small-scale farmers in South Africa lack access to technology, technical skills, and the financial resources necessary to implement precision agriculture practices. However, the most crucial aspect is that small scale farmers, cannot take advantage of the available technologies, services nor strategies, because policies and the associated extension services are inadequate (Aroba, 2023; Talaviya et al., 2020).

2.3. Socio-economic impact of precision agriculture

The adoption of AI technologies in precision agriculture holds the potential to realize socio-economic benefits through optimising resource use and minimizing input costs for small-scale farmers in South Africa (Ofori and El-Gayar, 2021). In addition, these technologies are likely to enhance resource efficiency and reduce input costs, supporting increased farm income, food security, and improvement of rural livelihoods (De Abreu and van Deventer, 2022; Lakshmi and Corbett, 2020). Precision agriculture enables precise application of fertilizers and pesticides concerning local soil and crop conditions, realizing high productivity and crop quality for high competitiveness in markets (Mizik, 2023). The economic resilience of the small-scale farmers will be improved. Furthermore, precision agriculture offers numerous other advantages, including sustainable farming practices and environmental conservation by reducing the environmental footprint of conventional agriculture. By reducing agrochemical use, soil erosion, and water wastage through targeted irrigation management, it mitigates the environmental impact and conserves natural ecosystems and biodiversity (Aroba, 2024; Tzachor et al., 2022).

3. Research methodology search strategy and research method

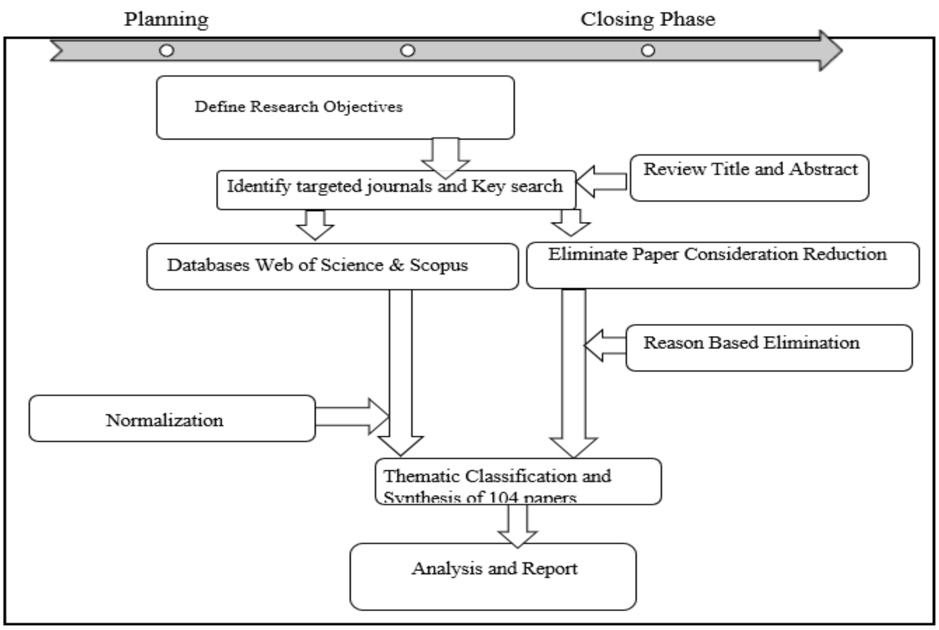

Figure 1. Systematic literature review planning chart (Anwana and Aroba, 2022).

This study applied a systematic approach using preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines and the bibliometric analysis to investigate the adoption of precision agriculture and its socio-economic implications for small-scale farmers in South Africa (Siregar et al., 2022). PRISMA ensures the convergence of information from various sources, enhancing the validity and reliability of the study's findings. The systematic literature review (SLR) method was used to conduct this investigation. Developing a well-structured search strategy is crucial for a systematic literature review (SLR) to ensure comprehensive coverage of the relevant literature. The search procedure involves creating precise and documented search approaches, including syntax such as field codes, parentheses, and Boolean operators, which are initially drafted in a text document and then transferred to bibliographic databases. This method helps researchers ensure the thoroughness, uniqueness, and relevance of their search strategy tailored to their research objectives. **Figure 1** below presents the flow diagram illustrating the search methodology used in this study.

4. Results

Table 1. Precision agriculture of small-scale farmers in Africa and South Africa (SA) provinces with their AI solutions.

Author/s, year	Challenges identified	Method/ Approach	Impact of AI on small scale farmers in Africa	Tools/Technology used for precision agricultural	South African Province	Farming Style	Solution
(De Abreu and van Deventer, 2022)	Decline in arable land, water scarcity, soil quality and pest infestations.	PRISMA analyzes 50 articles from 2015 to 2020 to understand the benefits of AI and IoT.	PA help optimize agricultural practices and resource usage.	Smart sensors, drones, big data, predictive modelling, and AI techniques of image recognition and neural networks	Not specified	advanced technologies to optimize field-level management	AI and IoT can significantly contribute to optimizing agricultural practices.
(Lakshmi and Corbett, 2020; Georgopoulos, Gkikas, and Theodorou, 2023)	Efficient food yield planning, prognosis, diagnosis, and treatment of ailments, and efficient management.	PRISMA to examine 38 articles from 225 relevant articles to identify the adoption of AI technologies in agriculture, livestock farming, and aquaculture.	Adoption of AI technologies can aid SSF.	Technologies mentioned include AI, ML, Deep Learning, the IoT, Big Data, and Cloud Computing.	Not specified.	Livestock farming, and aquaculture, with a focus on adopting innovative technologies like AI to improve productivity and sustainability.	To understand the factors that encourage and discourage the adoption of AI technologies, guide future research, and help stakeholders make informed decisions about integrating AI into their practices.
(Mohr and Kühl, 2021; Chougule and Mashalkar, 2022)	Food security, weather uncertainty, and population growth affecting crop yield.	AI Irrigation systems, weed management processes, and crop monitoring using embedded systems in robots and sensors.	Enhancing soil fertility and optimizing water utilization.	Utilization of robots for agricultural automation, soil water sensing techniques, and automated welding technology.	Not specified.	Shift towards more technologically integrated methods.	Efficiency of future-predictive facilities in running agricultural systems, resulting in cost savings and time optimization.

Table 1. (*Continued*).

Author/s, year	Challenges identified	Method/ Approach	Impact of AI on small scale farmers in Africa	Tools/Technology used for precision agricultural	South African Province	Farming Style	Solution
(Mtshali and Akinola, 2021)	Highlighting the need for effective land management and agricultural productivity.	The agri-park concept as a platform to stimulate local economic development through integrated and sustainable rural development models.	Low farming output	Not specified.	Harry Gwala District Municipality in KwaZulu-Natal.	Structured and community-based farming approaches through the Agri-park model.	Application of the Agri-park concept to enhance local economic development and address the challenges of land reform and agricultural productivity.
(Sampene et al., 2022)	Challenges of AI and technological issues.	Content analysis and case study approaches to evaluate AI 's development in Africa and its impact	AI has helped small-scale farmers in Africa, particularly in Kenya through Apollo Agriculture, which uses ML and remote sensing.	Use drones and robotics to monitor crop health, track pests, prevent diseases, and manage yields.	Kenya	Not specified.	AI can be a pathway to Africa 's transformation, recommending AI strategies.
(Foster et al., 2023)	Precision agriculture and smart farming technologies, such as bias, discrimination, and reinforcement of Western hierarchies of power.	The decolonialise mode of deliberation addresses the governance of smart farming and AI technologies indigenous ways of knowing and gender considerations in the development of these technologies.	AI and smart farming could offer opportunities for East African smallholder women farmers, but they also risk reinforcing existing hierarchies and disregarding Indigenous knowledge systems.	AI platforms mentioned include UjuziKilimo, Tulaa, AGIN, Apollo Agriculture, and the Farmers Companion App, which provide various agricultural data and insights to smallholder farmers.	East Africa	Not specified.	The use of mobile apps, SMS services, and other digital tools can enhance communication, access to markets, and knowledge sharing.
(Kombat, Sarfatti and Fatunbi, 2021)	The impact of climate change on agriculture, food, and nutrition security highlights the vulnerability of smallholder farming households due to limited resources and knowledge of adaptation and mitigation techniques.	Mixed methods were used to analyze the adoption of climate-smart agriculture (CSA) technologies by smallholder farming households.	Emphasizes the increasing knowledge of CSA technologies among smallholder farmers and the need for continuous generation of such technologies for positive outcomes.	CSA technologies, which may include precision agriculture tools, are being developed to help smallholder farmers adapt to climate change and mitigate greenhouse gas emissions.	Sub-Saharan Africa.	Predominantly smallholder farming.	Advocates for linking farmers, researchers, and extension practitioners to accelerate the adoption of CSA technologies, using bottom-up approaches to implement CSA actions effectively.

Table 1. (*Continued*).

Author/s, year	Challenges identified	Method/ Approach	Impact of AI on small scale farmers in Africa	Tools/Technology used for precision agricultural	South African Province	Farming Style	Solution
(Dibal et al., 2022)	Food insecurity, lack of access to modern technologies like IoT and cloud computing, and the high infrastructure cost in Sub-Saharan Africa (SSA).	Integration of IoT with cloud computing in Climate Smart Agriculture (CSA) to enhance food security in SSA.	IoT solutions can help in making accurate predictions and decisions, potentially benefiting small-scale farmers by reducing losses.	IoT, cloud computing, and Big Data analytics are mentioned as technologies used for precision agriculture.	Sub-Saharan Africa.	Small holder farming style.	Adopting IoT solutions for monitoring and optimizing agricultural processes, can lead to SSA becoming a net exporter of food.
(Munghemezulu et al., 2023)	UAV (Unmanned Aerial Vehicle) systems and high governmental regulations, slow down technology uptake. Limited flight time and maintenance needs of UAV systems also pose challenges.	Utilizes UAVs and spectral datasets for precision agriculture, with data collected from various projects across South Africa.	AI, through the use of UAVs, can provide high-resolution data for precision agriculture, aiding smallholders and emerging farmers in improving crop production and resource management.	Technologies include UAVs, multispectral bands, PIX4D mapper software, and Analytical Spectral Device (ASD) Field Spec spectroradiometer for data collection and processing.	South Africa	Precision agriculture, which involves the use of high-resolution imagery and spectral data to understand crop-soil-water variabilities and improve farming practices.	The development of a web-based data repository by the Agricultural Research Council-National Resources and Engineering (ARC-NRE) for easy access to UAV imagery, in line with institutional data-sharing policies. This would support long-term monitoring and aid in decision-making for farmers.
(Bala et al., 2021)	Challenges of technology, reliance on manual farming, drudgery, wastage, and low yields affecting agriculture in sub-Saharan Africa.	Designing an IoT-based autonomous robot system incorporating a camera and liquid-level sensor for remote monitoring and precision agricultural operations.	AI and IoT technologies are expected to revolutionize agriculture by improving crop yield and profit, reducing human labour, and enabling remote farm management.	Technologies used include IoT, fuzzy logic for robot navigation, Hough Transforms for ridge detection, and Node-RED with IBM cloud for the IoT platform.	Sub-Saharan Africa.	The farming style discussed is precision agriculture, which optimizes inputs and maximizes outputs through site-specific management.	The autonomous robot system that can navigate and perform tasks like irrigation and herbicide application, is monitored and controlled remotely via a web application.
(Obasi et al., 2024)	Challenges faced by African agriculture, such as climate change, soil health, and resource management.	The use of AI in spatial analysis and precision agriculture to address these challenges, emphasizing sustainable farming practices.	AI technologies are highlighted for their potential to improve decision-making, enhance crop yields, and promote economic growth for small-scale farmers in Africa.	Sensor-based monitoring, satellite imaging analysis, and machine learning algorithms as key AI tools for precision agriculture.	Broader African agricultural landscape.	South Africa	Adapting AI in precision farming can lead to creative, effective, and sustainable methods that enhance soil health and mitigate climate concerns.

Table 1. (*Continued*).

Author/s, year	Challenges identified	Method/ Approach	Impact of AI on small scale farmers in Africa	Tools/Technology used for precision agricultural	South African Province	Farming Style	Solution
(Twetwa-Dube and Oki, 2023)	The socio-economic and technological challenges that hinder the growth of precision agriculture in Africa.	Bibliometric Approach in precision agriculture to query the Web of Science and Scopus databases.	AI, IoT, help to improve agricultural productivity and efficiency for small-scale farmers in South Africa, helping them mitigate the impact of climate change.	IoT sensors, machine learning, and artificial intelligence as key technologies in precision agriculture that can provide real-time data for algorithms to boost productivity.	Africa as a whole.	Precision agriculture, which is a management concept that relies on intensive data collection and processing.	Allocating precision agriculture research by both government and private sectors in Africa. Suggest encouraging more research collaborations between Africa and North America.
(Gobezie and Biswas, 2023)	Data privacy, ownership, and the need for a sustainable business model.	PA data sharing and reward model called 'PrecisioNexion', which uses AI and blockchain technology to integrate PA data without compromising data privacy and ownership.	AI technologies, such as sensor-based computer visioning for on-site fertilizer recommendations, are mentioned as part of the diverse PA technologies.	PA technologies, including unmanned aerial vehicles (UAVs), remote sensing, proximal sensing, and data-fusion techniques.	South Africa.	Diverse farming systems in Africa, ranging from rainfed single crop-based mixed systems to irrigated expanses of land.	The Precision Nexion model is the proposed solution for streamlining PA data integration, incentivizing data owners, and fostering partnerships among stakeholders.
(Agboka et al., 2022)	Threats to maize production in Sub-Saharan Africa, such as insect pests and climate change, which impact food and nutrition security.	Hybrid fuzzy-logic with genetic algorithm and symbolic regression, to predict maize yield under different farming systems using climatic and edaphic variables.	AI algorithms, specifically symbolic regression, can accurately predict maize yield, potentially aiding smallholder farmers in East Africa by increasing their annual maize yield significantly.	AI algorithms like fuzzy logic and symbolic regression, combined with climatic and soil fertility data, to predict maize yield.	East Africa.	Maize–legume intercropping (MLI) and push-pull technology (PPT) as sustainable farming practices compared to traditional monocropping.	Adopting MLI and PPT leads to a substantial increase in maize yield, advocating for the upscaling of these sustainable farming practices through awareness and partnerships.
(Abbott et al., 2021)	Unpredictable rainfall, droughts, floods, and environmental degradation due to unsustainable agricultural practices.	Innovation in technology and knowledge production to improve water usage and land management. It emphasizes the need for smart farming solutions that consider technological constraints and regional variability.	AI for smart farming can potentially increase the efficacy of water usage and land management.	Information Communication Technologies (ICTs), Internet of Things (IoT), and artificial intelligence (AI) in smart farming.	Sub-Saharan Africa.	Not specified.	It emphasizes the need for innovation in technology and knowledge production to address challenges.

Table 1 provided discusses the integration of Artificial Intelligence (AI) and automation in modern agricultural practices, focusing on technologies such as automated robotic systems, drones, soil water sensing methods, and automated weeding techniques. The research papers underscore the potential benefits of AI in optimizing irrigation, pesticide, and herbicide applications, maintaining soil fertility,

and enhancing crop productivity and quality. They emphasize the need for tailored Machine Learning (ML) applications for small-scale farmers in Africa, addressing challenges such as data scarcity, lack of infrastructure, and the need for localized developmental implementation frameworks to support digital solutions. AI and ML technologies have the potential to improve yields, manage resources effectively, and reduce uncertainties in decision-making, which could greatly benefit small-scale farmers in Africa. However, these farmers face numerous challenges, including limited arable land, changing diets, increasing water demand, climate change, and pressures on the environment and soil health. Digital agricultural innovations tailored for low-middle-income countries and small-scale farmers highlight the importance of developing new approaches to make these innovations viable across value chains.

5. Benefits of AI-driven precision agriculture

Enhanced Agricultural Productivity: De Abreu and van Deventer (2022) highlight how precision agriculture, in combination with artificial intelligence technologies, can enhance small-scale agricultural productivity in South Africa. These AI-enabled solutions will help farmers improve the efficiency of water, fertilizer, and pesticide use, thereby increasing crop productivity and overall farm profitability (Ly, 2021).

Resource Efficiency and Cost Reduction: The adoption of precision agriculture with AI could be a pivotal intervention for creating an efficient resource consumption matrix for small-scale farmers in South Africa, aiming to reduce their operational costs. By leveraging AI algorithms that analyse data from satellite imagery, soil sensors, and weather forecasts, farmers can make informed decisions in real-time—helping them to save on input wastage and maximize output (Ahmad and Nabi, 2021; Kumar et al., 2022).

Risk Mitigation and Resilience: Sparrow et al. (2021) and Tzachor et al. (2022) indicated that precision agriculture has been applied to help small-scale farmers manage risks associated with climate variability, and manmade challenges, such as pests, and diseases. Advanced technologies and predictive analytic software have made it possible for farmers to anticipate potential threats to crops and, adjust their farming activities accordingly to ensure positive outputs.

Empowerment of Small-Scale Farmers: Lakshmi and Corbett (2020) reveal how the application of AI-driven precision agriculture tools enables small-scale farmers in South Africa to access the benefits of advanced technologies and decision-support tools. This democratizes information and knowledge, empowering small-scale farmers to overcome traditional barriers to market entry and compete effectively.

Societal Impact and Sustainable Development: A multiple deployment of AI-based precision agriculture is likely to bring about diverse positive societal impacts in South Africa, including poverty alleviation, food security, and rural development. Onyango et al. (2021) state that these technologies contribute to broader socio-economic and environmental impacts.

Knowledge Generation and Capacity Building: AI-driven precision agriculture plays a crucial role in knowledge generation and capacity building among farmers. This involves acquiring new skills and knowledge through participatory learning approaches and knowledge networks, enabling farmers to adapt to dynamic challenges and seize opportunities for innovation and growth (Mizik, 2023).

Policy Implications and Institutional Support: Georgopoulos et al. (2023) have shown that enabling policy frameworks and institutional arrangements foster the uptake of AI-driven precision agriculture among small-scale farmers in South Africa. Realizing the potential benefits of these technologies and creating an enabling environment for their deployment can further boost investment, innovation, and entrepreneurship in the agricultural sector, promoting inclusive and sustainable development.

6. Challenges and barriers

Although most small-scale farmers in South Africa find precision agriculture practices beneficial, several hurdles and challenges must be overcome for their effective and widespread adoption. These include technical, financial, institutional, and socio-cultural barriers that currently limit adoption and hinder the broader implementation of precision agriculture technologies across diverse farming communities.

Technological barriers: Sensor, drone, and data analytics technologies that support precision agriculture are often prohibitively expensive, and often not affordable to a small-scale farmer. In addition, the high initial investment and ongoing operational costs of such technologies pose major barriers to adoption, for resource-constrained farmers (Gokool et al., 2023).

Knowledge and skills gap: Transitioning to precision agriculture requires a certain level of technical knowledge and skills in data collection, analysis, and interpretation. Small-scale farmers often lack adequate training and capacity-building support to effectively use precision agriculture technologies (Georgopoulos et al., 2023).

Financial Constraints: Access to credit and financial services is so scarce that it limits the investment capacity of small-scale farmers even to technologies in precision agriculture. The high upfront costs associated with equipment, software licenses, and infrastructure for supporting connectivity, further discourage adoption of precision agriculture practices among small-scale farmers (Gardezi et al., 2022; Sampene et al., 2022).

Institutional and Policy Constraints: Lack of supportive/enabling policies, weak extension services, and the lack of or limited market linkages for small-scale farmers work hinder the adoption and spread of precision agriculture technologies. Institutional barriers such as inadequate infrastructure and regulatory frameworks disadvantage small-scale farmers, restricting their access to PA solutions (Tzachor et al., 2022).

Socio-cultural Factors: Socio-cultural norms, beliefs, and traditional farming practices act as barriers to the adoption of PA technologies. Resistance to change, scepticism towards innovative technologies, and a preference for conventional farming methods rooted in cultural heritage and community traditions hinder the adoption of PA technologies by small-scale farmers. These holistic strategies would blend technological innovation, policy support, institutional reform, and community engagement to meet the specific needs of small-scale farming communities in South Africa. These challenges can only be addressed through the combined efforts of governments, development agencies, research institutions, the private sector, and civil society organizations. Collaboration is essential to overcome barriers and unlock the full potential of precision agriculture in promoting inclusive agricultural development and sustainable livelihoods in rural areas (Chougule and Mashalkar, 2022; Georgopoulos et al., 2023; Tzachor et al., 2022).

This study applied a systematic approach using preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines to investigate the adoption of precision agriculture and its socio-economic implications for small-scale farmers in South Africa (Siregar et al., 2022). PRISMA ensures the convergence of information from various sources, enhancing the validity and reliability of the study 's findings. The systematic literature review (SLR) method was used to conduct this investigation. Developing a well-structured search strategy is crucial for a systematic literature review (SLR) to ensure comprehensive coverage of the relevant literature. The search procedure involves creating precise and documented search approaches, including syntax such as field codes, parentheses, and Boolean operators, which are initially drafted in a text document and then transferred to bibliographic databases. This method helps researchers ensure the thoroughness, uniqueness, and relevance of their search strategy tailored to their research objectives. **Figure 1** presents the flow diagram illustrating the search methodology used in this study.

The report flow is shown in **Figure 1**.

Figure 1 above shows the processes that are used for the documentation analyses. Due to limited research on precision agriculture in South Africa, the data extraction flowchart processing included African countries. In the subsequent phase, all documents that did not meet the inclusion criteria were excluded.

Table 2. Document types.

DOCUMENT TYPES			
Types	Scopus	Web of Science (WOS)	Total
Article	68	42	110
Book chapter	22	27	49
Conference paper	11	5	16
Conference review	5	2	7
Total	106	76	182

As shown in **Table 2** above, a crucial step in any systematic literature review (SLR) process is selecting relevant publications (Goagoses and Koglin, 2020). **Table 2** for this study displays the various document types that produced the 182 articles considered in this investigation. **Figure 2** below illustrates the percentage distribution of each publication type.

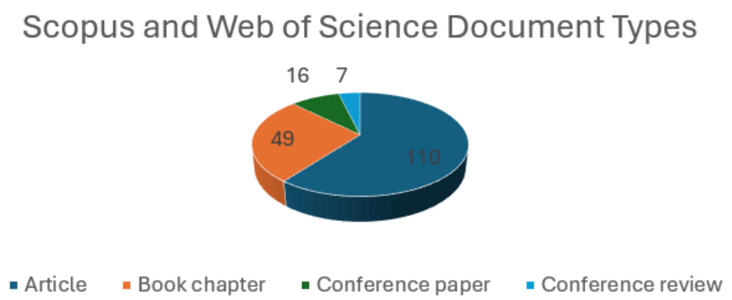

Figure 2. The percentages of publication of articles used for the analysis.

Table 3. Keyword search for Web of Science and Scopus library database.

Scopus	(TITLE-ABS-KEY (“small scale farmer” AND “Africa” AND “Societal impact”) OR TITLE-ABS-KEY (“Precision Agriculture” AND (“Artificial Intelligence” OR ai))) AND (LIMIT-TO (AFFILCOUNTRY , “Morocco”) OR LIMIT-TO (AFFILCOUNTRY , “Nigeria”) OR LIMIT-TO (AFFILCOUNTRY , “South Africa”) OR LIMIT-TO (AFFILCOUNTRY , “Egypt”) OR LIMIT-TO (AFFILCOUNTRY , “Tunisia”) OR LIMIT-TO (AFFILCOUNTRY , “Kenya”) OR LIMIT-TO (AFFILCOUNTRY , “Algeria”) OR LIMIT-TO (AFFILCOUNTRY , “Uganda”) OR LIMIT-TO (AFFILCOUNTRY , “Rwanda”) OR LIMIT-TO (AFFILCOUNTRY , “Ethiopia”) OR LIMIT-TO (AFFILCOUNTRY , “Zimbabwe”) OR LIMIT-TO (AFFILCOUNTRY , “Mauritius”))
Web of Science	(“small scale farmer” AND “Africa” AND “Societal impact”) OR (“Precision Agriculture” AND (“Artificial Intelligence” OR ai))

6. Study selection

Table 3 above presents the key search terms used in the process. Initially, 608 publications were identified using the bibliometric R-application. After additional screening to remove duplicates, 558 publications were excluded. Automated technologies identified an additional 68 records as ineligible due to insufficient keyword matches or not meeting specific search criteria. Furthermore, 268 entries were eliminated for various reasons, such as incorrect publication types. In total, 894 publications were excluded based on these criteria. Subsequently, 182 papers were selected for the study based on their compliance with the inclusion and exclusion criteria. To ensure the relevance of the abstracts to the study, the authors conducted a double-check/ed them. The selection process is shown in **Figure 3**, following the Preferred Reporting of Items for Systematic Reviews and Meta-Analyses (PRISMA) framework as per Aroba et al. (2020).

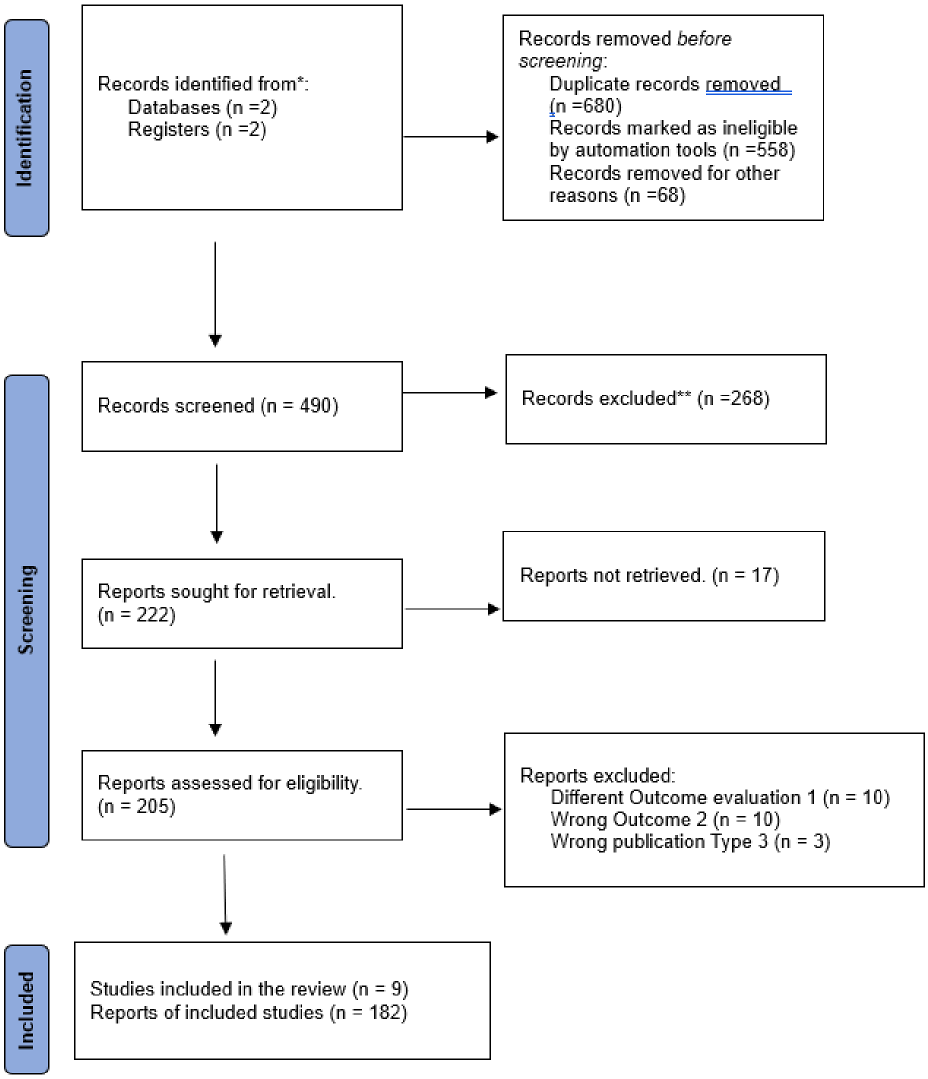

Figure 3. PRISMA extraction.

Figure 3 above illustrates the process flow of the extraction methods used in the PRISMA approaches deployed in this research.

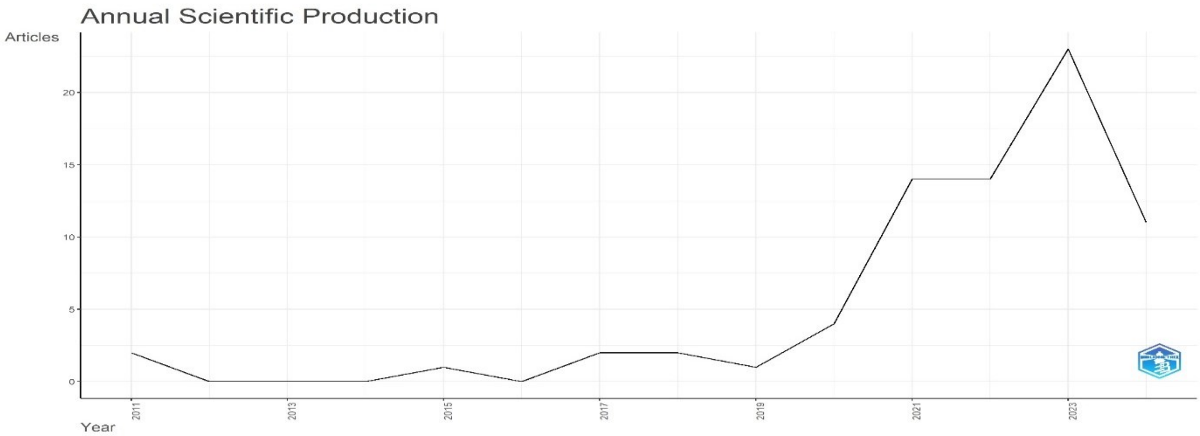

Figure 4. Annual scientific production from the inception of al agricultural precision using.

From **Figure 4** above, the results show that scientific output in PA has increased substantially from 2011 to 2023 whereas. PA in Africa has been more progressively applied from 2020 to 2024.

7. Recommendations for future research

There is limited research in South Africa concerning precision agriculture with the integration of artificial intelligence. There are many opportunities for research on AI-driven precision agriculture adopted by small-scale farmers (SSF) in South Africa, particularly focusing on the affordability and their impact on the livelihoods of small-scale farmers. More research and development are needed to design AI-driven precision agriculture tools that are user-friendly and accessible to small-scale farmers with minimal technical skills.

8. Conclusion

Precision agriculture holds promising potential for small-scale farmers, particularly in South Africa and in the entire Africa region. The integration of AI in precision agriculture holds immense promise for small-scale farmers in Africa. It can drive sustainable agricultural practices, enhance productivity, and contribute to economic and social development. Technologies such as crop mapping with satellite imagery and soil and plant sensors for assessing soil nutrient and water status show significant potential for enhancing crop management decisions at the farm level. The application of geographic information systems (GIS) and crop-soil simulation models has been tested, but majority of these technologies are still in the experimental stages. and their primary use has been in large-scale commercial farms in South Africa and Africa regions. Information on the application of PA technology in SSF for smallholder animal production systems is scarce. According to the published evidence, these practices which mostly include the use of sensors and geostatistical techniques are still in the experimental stages. AI and automation in modern agricultural practices are set to revolutionize farming methods, offering substantial benefits to small-scale farms across Africa. The integration of robotic systems, drones, soil water sensing technologies, and automated weeding technologies can optimize the application of irrigation, pesticides, and herbicides, improve soil fertility, and enhance crop yield and quality. The focus on critical issues affecting African agriculture, such as climate change, soil health, and resource management. AI technologies can be implemented in spatial analysis and precision agriculture practices to promote sustainability in farming. However, there is a concern about the potential risks associated with precision agriculture, including reinforcing unequal global power relations and unintended ecological consequences due to increased efficiency. To mitigate these risks, supporting self-sufficient agroecological farming and carefully considering the management, design, and scaled deployment of AI and ML technologies are crucial. Along with this is the requirement, a well-rounded, localized framework is needed to facilitate digital adoption among small-scale farmers in Africa. This requires collaboration among governments, private sectors, and farmers themselves. Encouraging outcomes have emerged from, several precision agriculture (PA) technologies tested in SSF.

However, addressing associated challenges and risks is essential to ensure equitable benefits and environmental preservation. Further research is needed, particularly in applying PA to smallholder animal production systems within SSF to optimize resource use efficiently. It was evident that some of the evaluated technologies require advanced technical knowledge and are not yet user-friendly Overcoming barriers like these is necessary before any widespread adoption of PA technology among small-scale farmers can occur. Currently, there is limited documented usage of these technologies among small-scale farmers. Nevertheless, PA technologies play a significant role in promoting sustainable agricultural development among SSF, who constitute a substantial portion of South Africa and Africa's agricultural production sector. With appropriate support, SSF can increase yields and competitiveness by reducing production costs without compromising sustainable practices.

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Abbreviations

Abbreviated Letters	Meaning
AI	Artificial Intelligence
IoT	Internet of Things
PA	Precision Agriculture
SSF	Small Scale Farmers
WoS	Web of Science
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
ML	Machine Learning
AGIN	Application Intelligence Application in Kenya
CSA	Climate Smart Agriculture
UAV	Unmanned Aerial Vehicle
ARC-NRE	Agricultural Research Council-National Resources and Engineering
ASD	Analytical Spectral Device
PIX4D	Professional photogrammetry and drone mapping
MLI	Maize–legume intercropping
PPT	Push-pull technology
SLR	Systematic literature review

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