International Journal of Multidisciplinary Research and Growth Evaluation.

Smallholder Agricultural Transformation and Sustainability in Sub-Saharan Africa: Socio-Cultural, Economic, and Environmental Perspectives

Mgcini Moyo [1*], **Never Assan** [2]

[1] Faculty of Humanities and Social Sciences, Department of Educational Foundations, Lupane State University, Lupane, Zimbabwe

[2] Zimbabwe Open University, Faculty of Agriculture, Department of Agriculture Management, Bulawayo Regional Campus, Bulawayo, Zimbabwe

* Corresponding Author: **Mgcini Moyo**

Article Info

ISSN (online): 2582-7138
Volume: 06
Issue: 04
July - August 2025
Received: 04-05-2025
Accepted: 09-06-2025
Published: 03-07-2025
Page No: 321-332

Abstract

Sustainable agricultural transformation in Sub-Saharan Africa (SSA) is essential for enhancing food security, improving the livelihoods of smallholder farmers, and promoting environmental sustainability. Together, these elements drive economic growth, social justice, and ecological resilience in the region. Achieving sustainable agricultural transformation in Sub-Saharan Africa demands a multifaceted approach that integrates socio-cultural, economic, and environmental perspectives to empower smallholder farmers. This review delves into the socio-cultural, economic, and environmental foundations of smallholder farming in Sub-Saharan Africa, highlighting the intricate interactions that influence agricultural sustainability. By adopting a holistic approach, this study investigates the interconnected factors impacting smallholder agriculture, underscoring the importance of sustainability, resilience, and inclusivity. The goal is to inform policies and interventions that support sustainable agriculture, enhance food security, and promote rural development, thereby contributing to the United Nations' Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action), and unlocking the transformative potential of smallholder farmers. In conclusion, as Sub-Saharan Africa continues to evolve, sustainable agricultural transformation will be pivotal in shaping the region's future. By prioritizing socio-cultural, economic, and environmental sustainability, smallholder farmers can drive growth, ensure food security, and build resilience in the face of climate change, in the long run contributing to a more prosperous and equitable future for generations to come.

Keywords: Smallholder Agriculture, Transformation, Sustainability, Socio-Cultural, Economic, Environment

Introduction

Smallholder agriculture is key to Sub-Saharan Africa's food security and economic growth, requiring productivity enhancements that prioritize environmental sustainability (Kamara *et al.*, 2019) [62]. With population projected to reach 1.5 billion by 2030, 2 billion by 2050, and 3.5 billion by 2100, this demographic shift could impact UN's Sustainable Development Goal 2 of ending hunger and ensuring food security (UN, 2022). Agricultural planning must consider how the region will feed itself and transform smallholder production to meet future demands. This transformation requires understanding the interplay of sociocultural, economic, and environmental factors shaping farming systems (Kapari *et al*. 2023) [63]. Misunderstanding these contexts has led to continued food crisis despite Africa's advantageous agricultural landscape and resources. Understanding social, economic, and environmental interactions is essential for developing effective policies supporting smallholder farmers. Agricultural Sustainability Transformation (AST) is critical as population growth surpasses food availability. SSA accounts for 204 million of 814 million people suffering from hunger, with low productivity and ineffective distribution systems as key factors (HLPE, 2013) [49]. The ongoing crisis requires reducing food waste and transforming food systems with solutions tailored to Africa's unique contexts. This crisis, worsened by epidemics, climate change, and gender inequality, threatens achieving SDGs in Africa.

Socio-cultural issues can serve as both obstacles and pathways to AST in SSA (Axon, 2020) [12]. Cultural beliefs and patriarchal power dynamics may restrict AST and intensify gender inequality, thereby impeding the progress of smallholder agriculture (Simon & Hasan, 2025) [108]. Gender inequality, defined by unequal treatment based on gender (Hernando *et al*., 2024; Doss, 2018) [48], significantly affects smallholder agriculture by influencing access to resources, opportunities, and decision-making power. In SSA, women's substantial contributions to agriculture are often underutilized, limiting their potential impact on the sector (Assan, 2015) [11], which could, in turn, impede AST. While assessing gender differences in agricultural productivity is complex, it is clear that the differing conditions and decision-making processes between women and men farmers affect output and incomes (Agarwal, 2012). Bridging these gender gaps is crucial for developing informed policies and practices that can transform smallholder agriculture. Enhancing the productivity of women farmers is essential for transforming smallholder agriculture; however, the impact of policies will vary by country, depending on local drivers of the gender gap (Abraham and Pingali, 2020; World Bank, 2012) [1]. Gender-sensitive indicators can guide targeted interventions for gender equality in agricultural policies, driving transformation in the smallholder farming sector.

The role of indigenous knowledge systems (IKS) in agricultural transformation continues to be a subject of debate within the realm of sociocultural issues (Saurav *et al*., 2023; Sow and Ranjan, 2021; Khatri *et al*., 2021). IKS holds the potential to significantly contribute to sustainable agricultural transformation, yet its effective implementation necessitates addressing various challenges and debates (Shubeena *et al*., 2022; Kereto *et al*., 2022; Naharki and Jaishi, 2020). It is specifically tailored to local contexts, deeply embedded in local cultures, and often incorporates traditional practices that support environmental sustainability and biodiversity, thereby promoting cultural heritage and community engagement (Borah *et al*., 2023; Liufu *et al*., 2023; Shai *et al*., 2022). A crucial perspective is that integrating modern agricultural science with local knowledge is essential for transforming smallholder agriculture (Hainzer *et al*., 2022) [44]. IKS encompass traditional practices suited to local environments and offer insights into climate-resilient practices (Kom *et al*., 2022). Cultural barriers can affect the adoption of new practices and technologies, as farmers may be wary of unfamiliar sources (Curry *et al*., 2021) [29]. For AST, involving local communities in decision-making is crucial. Context-specific solutions that honor local practices and socio-cultural contexts can foster sustainable development and enhance the livelihoods of smallholder farmers in SSA.

Economic challenges faced by smallholder farmers continue to pose significant barriers to the AST in SSA. These farmers are integral to African economies, making substantial contributions to agriculture, employment, and food security. Smallholder agriculture is crucial for poverty alleviation in developing countries and remains vital for GDP and employment in low-income nations (IDA (International Development Association), 2009). Economic growth within smallholder agriculture can enhance productivity, efficiency, and income levels. Income generation improves food security by enabling households to purchase essential goods and diversify income sources. Increased production has the potential to reduce consumer prices, thereby improving food access for impoverished communities (USAID, 2002). Despite their importance, smallholder farmers encounter challenges such as limited access to finance, markets, technology, and vulnerability to climate change. The sector faces difficulties due to climate change, restricted market access, low prices, and insufficient market information. Financial challenges include limited credit access, high interest rates, and a lack of financial services. Enhancing market access can increase income and stimulate local economies. Economic growth can lead to increased agricultural investment in irrigation, technology, and infrastructure. This research aims to identify solutions to overcome these challenges and unlock the potential for (AST)in SSA. Smallholder agriculture in SSA faces adaptation challenges in meeting the growing food demands.

Transformational change in agriculture to address climate change is inherently tied to sustainable development. This involves profound, long-term shifts in political, economic, social, or biological systems, fundamentally altering their structures and functions (Rotmans *et al*. 2004) [102]. Climate change results in extreme weather events, with severe effects in developing countries due to limited adaptive capacity (IPCC, 2014). Environmental disruptions from climate change hinder agricultural sustainability and affect smallholder farmers' production (Roudier *et al*., 2011; Dixon *et al*., 2003) [103, 32]. The resilience of smallholder farmers is compromised by environmental shocks and land degradation (Kelly and Adger, 2000). Climate shocks will impact agricultural production in African nations, leading to food insecurity (Vincent and Cull, 2014). Agriculture in Africa, predominantly managed by smallholder farmers, relies on rain, making it vulnerable to climate variations (Kurukulasuriya *et al*., 2006) [67]. These climate impacts vary across regions, affecting agriculture-dependent livelihoods. Evaluating farm-based livelihood vulnerability to climate shocks can help identify measures to enhance resilience and achieve sustainable development goals (SDGs). The first SDG aims to build the resilience of the poor by 2030, reducing exposure to extreme events and other shocks (Islam *et al*., 2014) [55]. Climate impacts on crops and livestock result in significant production reductions, with economic impacts exceeding global data. Climate-induced droughts and floods lead to agricultural losses, affecting rural communities and food security. Exploring farmers' coping strategies is essential to adapt to changing conditions for agricultural sustainability. Targeted interventions are necessary to enhance the resilience of smallholder farmers and ensure sustainable practices amid climate challenges.

Africa's Smallholder Agricultural Future: Debating Sustainability Transformation

Transforming smallholder agriculture towards sustainability is a multifaceted endeavor, influenced by various factors that can impede or expedite progress. Africa stands at the forefront of this challenge, with an opportunity to pioneer sustainable agricultural development that harmonizes socio-cultural and economic advancement with environmental stewardship, ultimately driving rural development and uplifting the majority of its population. This article examines the socio-cultural, economic, and environmental dimensions of sustainability in smallholder agriculture in sub-Saharan Africa (SSA), recognizing the intricate relationships between these factors and human well-being. Understanding sustainability is crucial in this context, given its intersection with economic, social, and environmental factors impacting human well-being (Sundas *et al*. 2024). Agricultural development is vital for poverty reduction and improved food security in developing countries (Viana *et al*. 2022). However, SSA uniquely faces stagnant per capita agricultural productivity over the past four decades (AGRA, 2020). The increasing demand for agricultural commodities has led to resource misappropriation and exploitation, resulting in biodiversity loss, land degradation, and pollution (Tumawu *et al*. 2025; Amirahmadi, *et al*. 2024). AST in Africa necessitates a holistic framework that balances sustainability, resilience, and inclusivity to drive meaningful change (Hofstetter, *et al*. 2022; IFAD, 2020). By examining the Socio-Cultural, Economic, and Environmental dimensions of sustainability, this article aims to contribute to the discourse on AST in SSA.

Smallholder farmers make up a significant portion of the rural poor globally, particularly in South and Southeast Asia and SSA (Birthal *et al*. 2005) [21]. Despite their efficiency in resource use, many smallholders remain impoverished due to limited access to technical and economic opportunities (Touch *et al*. 2024; Muzari *et al*. 2012) [115, 82]. This is especially true in Africa, where stagnant agricultural productivity over the past four decades has exacerbated food insecurity, reliance on food aid, and poverty. Food insecurity, a key indicator of poverty, remains a pressing challenge for the continent (Otekunrin, *et al*. 2020) [90]. By advocating for innovative practices, technologies, and policies, AST seeks to stimulate rural development, enhance food security, and improve the economic and social well-being of rural communities (Ravazzoli and Valero, 2020) [100]. By promoting sustainable agricultural practices, AST can increase crop and animal yields, improve food availability, and reduce hunger and malnutrition. AST has the potential to create employment, increase income opportunities, and enhance living standards in rural areas, thereby contributing to overall economic growth (kamara *et al*. 2029) [62]. Sustainable agricultural practices can aid in mitigating climate change, conserving biodiversity, and protecting natural resources. AST aligns with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action). By achieving these outcomes, AST can contribute to a more sustainable, equitable, and prosperous future for Africa's rural populations (Abraham, and Pingali, 2020) [1].

The discourse surrounding the transformation of agricultural sustainability in Africa is complex and multifaceted, influenced by a diverse array of factors, including social, cultural, religious, economic, and environmental considerations (Figure 1). This topic has often been oversimplified, neglecting to account for the continent's diverse social, cultural, religious, economic, and environmental characteristics, and the significant impact these factors can have on smallholder agriculture (Byerlee *et al*. 1992) [26]. The term "sustainable" has historically been used imprecisely, and researchers in agriculture have emphasized increasing productivity in a sustainable manner (Petersen & Snapp, 2015), often overlooking social sustainability components such as indigenous knowledge systems and gender roles and equity (Zurek *et al*., 2015).

Several studies (Bezner Kerr, 2008; Croppenstedt *et al*., 2013; Kilic *et al*., 2015) indicate that males possess a disproportionate degree of influence over agricultural assets and receive a larger share of the benefits, for example. Consequently, academics are placing increased emphasis on the necessity of an expanded and inclusive Sustainable Agricultural Intensification (SAI), taking equality and equity into account (Loos *et al*., 2014). This includes the manner in which labor requirements for intensification will be distributed, as well as crop rights and gender-specific and age-biased access to land (Snyder and Cullen, 2015).

The structure of agro-ecological zones is pivotal in shaping the transformation of agricultural sustainability and, consequently, the strategies required to implement innovations within the sustainable smallholder farming sector, which serves as the backbone of agriculture and food production in Africa. Africa, in particular, possesses significant potential for developing various sustainable agricultural innovations to enhance its growth and development, grounded in the social, cultural, religious, economic, and environmental drivers of agricultural sustainability. By transforming agricultural sustainability, Africa could improve its food systems from the demand side while also mitigating the effects of climate change.

The concept of sustainability in the agriculture-food system and the food supply chain can be characterized as a harmonious equilibrium between the effective utilization of valuable resources (UNEP, 2016). These resources include agricultural land, water, fuel, and so on; greenhouse gases, e.g., carbon dioxide, methane, carbon monoxide, and others; and social and economic issues and ethical considerations as an integral component that ensures the survival of subsequent generations (Flachowsky *et al*., 2017). Figure 1 highlights the diverse socio-cultural, economic, and environmental dimensions that influence the trajectory of sustainable smallholder farming. The discussion focuses on socio-cultural, economic, and environmental factors influencing smallholder agriculture in SSA, while also acknowledging the significant roles of technological and policy environments in shaping sustainability and transformation of food systems (IPES, 2015). The livestock industry is one of the sectors with the highest ecological footprint, making an understanding of sustainability essential Assan, 2025) [11]. A viable agricultural system, in accordance with the Food and Agriculture Organization, should develop beneficial effects across all three dimensions simultaneously: economic, social, and environmental (Ingra, 2011) [51]. For Africa, the ongoing food crisis presents an opportunity that must not be overlooked, underscoring the need for context-specific AST solutions.

Africa's persistent food crisis, exacerbated by recent pandemics and increasingly by climate change, is further burdened by socio-cultural barriers such as gender disparities in agriculture and food production, posing significant threats to achieving the SDGs in SSA (Figure 1). AST is essential for Africa's survival at every stage of population evolution, whether in industrialized or impoverished nations, rural or urban areas, villages or metropolises. It is a misconception to believe that cutting-edge research or the latest developments are the sole sources of AST unless such research and technology are tailored to the needs of the smallholder farming sector. The discussion highlights that unlocking the potential of smallholder farmers as catalysts for AST in Africa requires a deep understanding of the complex relationships between the socio-cultural, economic, and environmental aspects of their farming practices, livelihoods, and ecosystems.

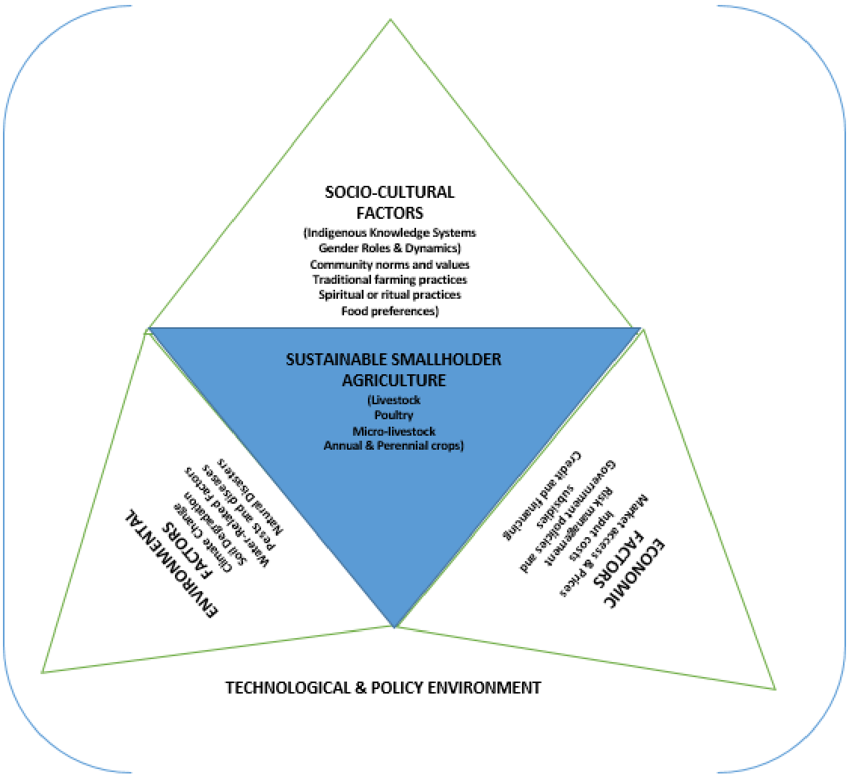

Fig 1: Balancing Socio-Cultural, Economic, and Environmental Aspects for Sustainable Smallholder Agriculture

The fundamental premise of sustainability is that SSA ought to meet its core requirements while also protecting its innate surroundings. As a result, it is possible for the following generations to survive solely on their own (Aavik *et al*., 2017; Manhaes *et al*., 2018). Smallholder agricultural activities require careful planning to ensure environmental sustainability (Munonye and Eze 2022), with the aim of maintaining ecosystem harmony and promoting sustainable development that benefits the population. Balance and sustainability measures in African food systems, notably those from the broader cultural and interpersonal aspects of smallholder crop and livestock farming, present substantial challenges compared to standard indices (e.g., the quality of water participation of stakeholders or output from farming growth) due to their intrinsic complexity.

Agricultural Sustainability Transformation in Africa: Insights from a Smallholder Farmer Socio-Cultural Perspective

Local communities' socio-cultural contexts are frequently overlooked or misinterpreted, despite their potential to drive sustainable agricultural transformation (Assan, 2023) [11], thereby limiting the impact of AST initiatives in Africa. External interventions often overlook the importance of traditional practices, social norms, and cultural values that are essential for community adoption and ownership of sustainable agriculture practices. This study takes a socio-cultural approach to investigate the intricate factors affecting smallholder farmers' capacity to lead sustainable agricultural transformation in Africa (Assan, 2023) [11]. This research seeks to understand the cultural, social, and economic factors influencing smallholder farmers' decisions and practices, with the goal of identifying opportunities and challenges and informing policies that support their contributions to sustainable agriculture and rural development.

Transforming African Agriculture: A Gender Perspective on Sustainability

Smallholder agriculture is heavily influenced by gender dynamics, which are shaped by the distinct social and biological roles of men and women (Assan, 2015) [11]. In SSA, small-scale farming is crucial for the livelihoods of resource-poor communities, playing a significant role in socioeconomic development and food security. Numerous studies have explored women's disempowerment from both social and economic angles, as well as the initiatives aimed at fostering empowerment (Desai and Krishnaraj, 2004; Kabeer, 2001; Jejeebhoy & Sathar, 2001; World Bank, 2001b; Pulerwitz, Gortmaker, & DeJong, 2000) [30, 61, 58, 93]. Over time, discussions on gender (in) equality in smallholder agriculture have increasingly centered on addressing gender disparities and promoting equality to enhance agricultural productivity and growth across the continent. Agricultural development specialists and gender activists have underscored the struggles, resilience, and agency of women as they navigate societal expectations, patriarchal structures, and cultural barriers that impede empowerment and affect agriculture.

The agricultural sector in SSA is vital for local and regional economies, food security, and employment, particularly for women. Studies consistently reveal that female farmers have lower agricultural productivity than their male counterparts due to inequitable access to agricultural inputs, such as family labor, high-yield crops, pesticides, and fertilizer. Equalizing women's access to these inputs and increasing their returns is crucial to closing gender gaps in agricultural productivity, potentially increasing crop production by up to 19%, boosting agricultural and overall GDP, and lifting hundreds of thousands out of poverty (World Bank 2001a; Mason & Smith, 2000) [74].

Gender inequality and restricted access to resources for women profoundly impact smallholder agriculture in Africa, a sociocultural factor that has hindered smallholder farming (Hernando, *et al*. 2024) [48]. In societies where patriarchy prevails, men's dominance has led to women being marginalized in terms of access to agricultural production resources, significantly affecting food production in smallholder agriculture (Walby, 2002) [21]. This system reinforces discriminatory attitudes and beliefs, granting men the power to act on them (Andersen, 2006) [4]. Consequently, women may be denied equal rights and opportunities in smallholder agriculture or face discrimination in other areas beyond agriculture. Gender inequality can contribute to food insecurity, as women's limited access to resources can impact their ability to produce and access nutritious food. This limited access can perpetuate poverty among rural households, restricting their ability to improve their livelihoods. Addressing gender inequality is essential to accelerate the AST agenda in SSA, which can help the continent achieve the SDGs of food security and gender equality.

Cultural norms dictate the roles of men and women in animal production, and gender-differentiated roles, knowledge, and preferences vary among different gender groups (Piri *et al*., 2021) [2]. In many societies, gender-based discrimination and inequality limit women's participation in decision-making processes related to animal production, leading to an unequal distribution of resources and opportunities (Yasehak (Makoka *et al*., 2018). Therefore, recognizing and addressing these challenges is essential to ensure the sustainable development of animal production and food security. When gender inequality exists in smallholder agriculture, it results in unequal outcomes in food and agricultural production, leading to food and nutritional insecurity that affects not only those targeted due to their gender but also the broader rural economy, thereby hindering overall development and growth. Women's limited access to resources like land, credit, and technology can often reduce their productivity and overall farm output, perpetuating food insecurity in many rural areas (Adebayo and Worth, 2024) [3]. Due to male dominance, women have limited decision-making power in agriculture, which can restrict their ability to adopt new agricultural practices and technologies for crops or livestock (Assan, 2015) [11].

Africa's Indigenous Knowledge: A Key to Sustainable Agricultural Transformation

Indigenous knowledge (IK) and Indigenous Knowledge Systems (IKS) are terms scholars use to describe the knowledge and systems within local communities and societies (Malapane *et al*. 2024; Kugara *et al*. 2022) [71, 66]. These systems are distinct due to their social, cultural, and ideological contexts, developed through the ecological, geographic, and sociological conditions unique to indigenous cultures. Indigenous knowledge in smallholder farming systems has been successful for centuries, serving as a foundation for innovation in Africa. The debate on indigenous knowledge systems' role in agricultural sustainability transformation in Africa has been contentious, with researchers divided on their usability. However, the discourse is shifting towards recognizing the benefits of indigenous knowledge systems, particularly in agriculture amid a changing climate. Indigenous crop and livestock knowledge has also evolved to tackle climate vulnerability, animal health, water conservation, and seed systems. Promoting indigenous knowledge systems is essential for mitigating impacts, which includes recognizing and valuing them, documenting and preserving them, and supporting their integration with modern agricultural practices. Indigenous knowledge systems are closely linked to cultural heritage, and their neglect can result in the loss of cultural identity and traditional practices.

The role of Indigenous Knowledge Systems (IKS) in climate change has been highlighted in various studies (Kugara *et al*. 2022) [66]. Bol and van Niekerk (2023) [23] provided insights into the African indigenous understanding of the climate change and disaster risk nexus and geohazards as part of multidisciplinary and integrated approaches to climate change action. There is a need for climate change experts to reconsider the role of indigenous knowledge systems in climate change adaptation and governance to achieve the Agricultural Sustainability Transformation (AST) agenda in Africa (Kavu *et al*. 2022) [64]. Indigenous knowledge systems often offer valuable insights into climate-resilient practices, and their neglect can diminish smallholder farmers' capacity to adapt to climate change. These systems frequently include traditional practices and techniques well-suited to local environments, making their loss potentially harmful to agricultural productivity. They often promote crop diversity, and their absence can lead to reduced diversity, increasing smallholder farmers' vulnerability to pests, diseases, and climate change.

African agricultural production is predominantly sustained by small-scale farmers, each managing less than 5 hectares (Kamara *et al*., 2019) [62]. These farmers have historically ensured the continent's food supply through a wealth of indigenous knowledge (IK) that effectively leverages both natural and socio-economic production factors (Uma *et al*., 2015). To transform African smallholder agriculture, it is essential to consider the local farmers, who possess their own agricultural expertise and knowledge. Implementing significant changes without incorporating their insights could marginalize them, thereby hindering efforts to enhance smallholder farming. Not all traditional knowledge is outdated; some have been adapted to be beneficial. Despite the advent of modern farming techniques, many smallholder farmers in Africa continue to rely on indigenous practices, either independently or alongside modern technologies (Kamara *et al*., 2019) [62].

Small-scale, resource-poor farmers have valid reasons for adhering to their traditional knowledge and associated farming practices, and modern technologies will only be effective and sustainable if they incorporate the local understanding of cultural, social, and ecological systems (Assan, 2023) [11]. Current literature underscores the widespread significance of indigenous knowledge in agriculture (Drissi 2023; Melash *et al*. 2023; Qwabe, 2020; Sharma *et al*. 2020) [34, 78, 94, 106]. This knowledge not only encompasses local soils, flora, and fauna but also holds intrinsic value in mitigating and adapting to climate change, as highlighted by Nyong *et al*. (2007) [86], Smith and Sharp (2012) [111], and Makondo and Thomas (2018). Indigenous knowledge approaches can be applied for various purposes, such as climate monitoring (Speranza *et al*. 2010) [112], soil fertility improvement, nitrogen fixation, food security during droughts, and organic inputs for soil and pest management. These methods are culturally appropriate, cost-effective, and utilize local resources (Gorjestani 2000) [42]. They also enhance agricultural sustainability (Lwoga *et al*. 2010) [69], climate change adaptation, and food security. Seasonal climate prediction and adaptation using indigenous knowledge systems in southern African agriculture have proven useful (Jiri *et al*. 2016) [60]. Indigenous knowledge systems often provide valuable insights into climate-resilient practices, and their neglect can diminish smallholder farmers' ability to adapt to climate change. Examples include compost mounds, agroforestry techniques, indigenous plants, and organic inputs (Mbow *et al*. 2019) [77]. It is possible to reconcile indigenous knowledge with scientific assessments of soil fertility changes in the smallholder farming sector (Gray and Morant, 2003) [43].

The international community is advocating for the integration of indigenous knowledge into climate change data and sustainable agriculture for smallholder farmers (Ford *et al*. 2016; Altieri and Nicholls, 2017) [39]. Mazzocchi (2006) [76] highlighted that, despite the differences between Western science and traditional knowledge, these diverse forms of knowledge can learn from one another. The imposition of external technologies and practices can be unsuitable for local contexts, leading to decreased productivity and sustainability. Moyo (2009) [80] contended that indigenous knowledge-based farming practices challenge notions of modernity, development, and progress. Modern agricultural crop science has resulted in a reduction of crop diversity, adversely affecting smallholder crop farming systems under the guise of improved yield, while undermining the vulnerability and resilience of food systems. Previous seed production mechanisms aimed to ensure continuity of production at a low cost, despite average yields. Understanding and preserving indigenous agricultural knowledge is proposed as a way forward for future research (Radcliffe and Parissi, 2022) [96]. Science must embrace traditional and indigenous knowledge to address our biodiversity crisis (Ogar *et al*. 2020) [87]. The integration of indigenous and scientific knowledge is essential for sustainable agricultural extension and production, addressing both strengths and challenges (Radcliffe *et al*. 2020) [99].

Recent scholars have acknowledged traditional indigenous knowledge and nature protection as a cultural concept (Andersson, *et al*. 2021) [6]. Managing digitized indigenous knowledge systems in repositories will be crucial for their usability in smallholder agriculture (Balogun, 2023; 2021) [14-15]. However, due to negative perceptions from external forces, this has not materialized, primarily due to a lack of funding. External funders do not view this as a worthwhile endeavor, compromising the usability of indigenous knowledge in the smallholder farming sector. The imposition of external technologies and practices can be unsuitable for local contexts, leading to reduced productivity and sustainability. Although technology is becoming more affordable for farmers, many smallholders face challenges with initial investments, such as the high costs of essential tools like mobile farming applications and soil sensors (Dhillon and Moncur, 2023) [31].

Indigenous agricultural practices are crucial for maintaining biodiversity (Sharma *et al*. 2020) [106]. Research has confirmed that local plants are used in ethno-veterinary treatments, which have been shown to enhance the health and productivity of livestock and poultry by improving feed consumption, body mass, carcass dimensions, and quality (Maroyi, 2021; Jambwa *et al*. 2021) [72, 56]. Ethnoveterinary medicines are gaining popularity over traditional pharmaceuticals because they are more accessible, cost-effective, and perceived as effective. Traditional livestock management practices exemplify non-exploitative and environmentally friendly farming methods, contributing to sustainable livestock and poultry development. Sithole (2020) [110] explored the use of indigenous knowledge systems in crop and livestock production and their implications for social ecology, finding that indigenous tree ashes and leaves are used to improve soil quality, preserve food, treat livestock, and act as organic pesticides for various crops. In livestock production, Indigenous Technical Knowledge (ITK) is crucial for promoting sustainable and resource-efficient practices. Smallholder farmers have employed local knowledge, such as maintaining good hygiene, using herbs, relocating from infested areas, self-diagnosis, manually removing ticks, lice, and worms, burning infested pastures, and sharing herds, in their livestock production practices (Ayoade *et al*. 2020) [13].

Indigenous knowledge systems encompass traditional practices and techniques that are finely tuned to local environments, and their loss could be detrimental to agricultural productivity. These systems often encourage crop diversity, and their absence may result in reduced crop variety, heightening smallholder farmers' susceptibility to pests, diseases, and climate change. Disregarding or suppressing indigenous knowledge systems can profoundly impact the transformation of smallholder agriculture on the continent. To mitigate these effects, it is essential to acknowledge and appreciate indigenous knowledge systems (Malapane *et al*. 2024) [71]. This requires the integration, documentation, and preservation of indigenous knowledge. Indigenous agricultural knowledge is a crucial yet underappreciated human-based resource for sustainable smallholder agriculture in Africa. The value of indigenous knowledge systems can be realized by facilitating their integration with modern agricultural practices. Community-based agricultural approaches that encourage participatory methods involving indigenous communities in decision-making processes in agricultural research are likely to be successful (Barakabitze, *et al*. 2017) [16]. By recognizing the importance of indigenous knowledge systems, smallholder agriculture can become more resilient, sustainable, and culturally relevant.

Economic Empowerment of Smallholder Farmers: A Pathway to Sustainable Agricultural Transformation in Africa

Smallholder farmers are the backbone of Africa's agricultural sector, playing a crucial role in food production, rural employment, and economic growth (Nyambo *et al*., 2022) [85]. Despite their importance, they encounter numerous economic challenges that impede their productivity, profitability, and potential for sustainable agricultural transformation (FAO, IFAD, UNICEF, *et al*., 2019). This research delves into the economic dynamics of smallholder farming systems in Africa, focusing on opportunities and challenges for sustainable agriculture, livelihood improvement, and economic development. Smallholder farmers make significant contributions to African economies, particularly in the agricultural sector, employment, and food security (Jayne *et al*., 2016) [57]. However, they face challenges such as limited access to finance, markets, technology, and vulnerability to climate change (Jayne *et al*., 2016; Dzanku *et al*., 2015; Ellis and Freeman, 2004; Dorward *et al*., 2004) [57, 35, 33]. By understanding these dynamics, this research aims to identify solutions to overcome these challenges and unlock the potential of smallholder farming in Africa.

Investing in smallholder farming has the potential to unlock significant growth, boosting agricultural productivity, household income, and rural economies (Kamara *et al*., 2019) [62]. This investment can increase access to modern farming techniques, technology, and inputs, leading to higher crop yields and improved productivity (Rosegrant *et al*., 2025) [101]. Consequently, food security and nutrition can be enhanced through increased food production, improved access to diverse and nutritious food, and promotion of sustainable agriculture practices (HLPE, 2013) [49]. Additionally, investing in market infrastructure and food safety measures can expand market access for farmers and reduce foodborne disease risks. As productivity and yields improve, smallholder farmers can increase their income, enabling investments in their farms, households, and communities (World Bank, 2012). Conversely, inadequate investment in smallholder farming has hindered Africa's agricultural transformation, limiting productivity and potential, and constraining economic development (Touch *et al*., 2024) [115]. By prioritizing smallholder farming investments, governments, organizations, and private sector entities can stimulate growth, contributing to improved agricultural productivity, household income, and rural economies (World Bank, 2012).

Smallholder farmers encounter substantial hurdles due to limited access to finance and credit, which severely impacts their agricultural productivity and overall well-being (Swinnen and Maertens, 2010; Ruiz Navajas, 2001) [114, 104]. The lack of collateral, formal records, and financial literacy further complicates their ability to secure insurance and savings, leaving them vulnerable to risks and shocks (Khan *et al*. 2024) [65]. This financial constraint limits their capacity to invest in essential farm inputs, technologies, and sustainable practices, ultimately affecting crop yields and income (Giller *et al*. 2021) [40]. Moreover, smallholder farmers face significant challenges in accessing markets, including limited market information, weak bargaining power, and inadequate infrastructure, such as transportation, storage, and processing facilities. As a result, they struggle to sell their produce at competitive prices, exacerbating their vulnerability to economic and environmental shocks and compromising their resilience and livelihoods.

The high costs of sustainable technologies and practices pose a significant barrier to adoption for smallholder farmers, hindering their ability to implement environmentally friendly methods (Wakweya, 2023) [120]. Sustainable inputs like organic fertilizers and pest control methods are often pricier than conventional alternatives, increasing production costs and potentially leading to reduced income, debt, and decreased competitiveness (Mathieu *et al*., 2022) [75]. This can also result in environmental degradation and limited market access. To address these challenges, solutions such as subsidies, affordable financing, training, and market incentives can facilitate the adoption of sustainable practices (Dhillon and Moncur, 2023) [31]. Policy instruments, including those promoting Climate Smart Agriculture (CSA), can also encourage smallholder farmers to adopt sustainable practices (van Asseldonk *et al*., 2023; USAID, 2016) [118]. Governments and organizations can provide subsidies and incentives to support smallholder farmers in adopting sustainable technologies and practices, ultimately enhancing their livelihoods and contributing to environmentally friendly agriculture.

Smallholder farmers often have insecure or unclear land tenure and rights, due to weak land governance, customary laws, or gender discrimination (Nara *et al*. 2021) [83]. Without secure control over land, farmers may be less likely to invest in their land, leading to reduced productivity and crop yields. The lack of control over land can lead to reduced income and increased poverty for farmers and their families. This affects their ability to use their land as an asset, to access credit, to adopt long-term soil conservation measures, or to benefit from land value appreciation. Women smallholder farmers often face gender-based discrimination, limiting their access to land ownership and control that has impacted indirectly on agricultural production. The failure to control land for agricultural production can have significant economic implications for farmers, communities, and the broader economy. Reduced agricultural productivity and limited access to land can lead to food insecurity, particularly for vulnerable populations

An Environmental Lens on Smallholder Agriculture: Driving Sustainability and Transformation

Africa's agricultural sector is grappling with significant challenges, including climate change, land degradation, and environmental sustainability concerns (Montanarella, *et al*. 2018) [79]. Smallholder farmers, who play a vital role in food security and rural development, are particularly susceptible to these challenges. Land degradation, driven by human-induced processes such as climate change, affects 3.2 billion people globally, leading to long-term declines in biological productivity, ecological integrity, and human well-being (Andersson, *ET AL*. 2011; Stocking, *et al*. 20010) [5, 113]. Smallholder farming systems face pressing issues like soil degradation, water scarcity, and climate change, which threaten their long-term sustainability and productivity. Climate Change has caused rising temperatures, shifting precipitation patterns, and more frequent extreme weather events are impacting smallholder farmers' productivity and livelihoods (Warren *et al*. 2018) [122]. Climate-related stressors can result in lower crop yields and animal productivity, decreased water availability, and reduced soil fertility (Climate Change 2022). Smallholder farmers often lack the resources and infrastructure to adapt to climate change, making them more vulnerable to crop and animal failures, reduced income, and increased poverty. Climate-related shocks can lead to food shortages, price volatility, and decreased access to nutritious food, particularly for vulnerable populations (Owino *et al*. 2022; Glopan, 2020) [91, 41]. In this context, supporting smallholder farmers' resilience and adaptability is crucial for ensuring food security, improving livelihoods, and promoting sustainable agricultural development.

Water scarcity, driven by climate change and inefficient usage, has severely affected agricultural productivity (Ingrao *et al*. 2023) [51], leading to food shortages and malnutrition (FAO, 2020). Both crop yields and livestock health are compromised, impacting food availability and farmer incomes (Biswas *et al*. 2025) [22]. Climate change, overexploitation of groundwater, and population growth are exerting significant pressure on natural water sources, posing a serious threat to various sectors of society, particularly the sustainability of smallholder agriculture due to its reliance on rain-fed agriculture (Biswas *et al*. 2025) [22]. Future projections of freshwater availability suggest that agricultural production will face a significant global shock, especially affecting the African smallholder farming sector, thereby threatening food security and sustainability. To combat this, implementing sustainable water management practices and climate-resilient agriculture is crucial (UNESCO, 2023). This includes techniques like rainwater harvesting, water recycling, and conservation agriculture, which can enhance water efficiency, reduce waste, and boost agricultural productivity (Zhang *et al*. 2021) [127].

Climate variability is causing biodiversity loss, endangering indigenous plant and animal genetic resources vital for sustainable agriculture (Brubacher *et al*. 2024) [24]. This loss jeopardizes food security, particularly for vulnerable communities' dependent on local crops and livestock, and undermines efforts to achieve sustainable agricultural transformation (Annappa, *et al*. 2023) [7]. Without genetic diversity, crops and livestock are less resilient to climate change. Conservation efforts, including the protection of genetic resources, promotion of agroecological practices, and implementation of supportive policies, are essential to preserving biodiversity and ensuring long-term food security and ecosystem health (Hébert, 2025) [46]. Balancing productivity with environmental risks presents challenges for smallholders (Nassary, 2025) [84]. Emerging technologies, such as precision agriculture, genetic innovations, and drone technologies, offer promising solutions to optimize resource use, enhance crop resilience, and enable real-time monitoring, thereby supporting sustainable agricultural practices.

Land degradation poses a significant threat to the African continent, resulting in soil loss, biodiversity loss, and degradation of natural resources (FAO, 2021). Africa accounts for 65% of global cropland degradation, affecting at least 485 million people and costing $9.3 billion annually. The interconnectedness of environmental degradation, poverty, and agriculture is a significant concern, particularly in developing nations (Olanipekun *et al*., 2019) [88]. Land degradation affects 3.2 billion people globally, resulting in long-term reductions in biological productivity, ecological integrity, and human value (IPCC, 2019). This loss of biodiversity and ecosystem services accounts for over 10% of global annual gross products (Scholes *et al*., 2018) [105].

The main causes of land degradation in Africa include deforestation, conflicts, inadequate soil management, shifting cultivation, land tenure insecurity, and variations in climatic conditions (Chikanda, 2009; Ji *et al*., 2024; Bugri, 2008) [27, 25]. Poor farmers are disproportionately affected, and demographic growth, conflicts, and inherent characteristics of fragile soils in different agro-ecological zones exacerbate the issue. Africa has an estimated additional 132 million hectares of degraded cropland, making millions more vulnerable (FAO, 2021). Around 45% of Africa's land is impacted by desertification, with 55% at very high risk of further desertification.

Land degradation threatens livelihoods and is influenced by economic, social, and environmental factors, limiting the poverty-reducing effects of economic growth and agricultural reforms (Barbier, 1997) [17]. The world's population growth will lead to increased demand for new cropland, putting pressure on land and resulting in land degradation (Colby, 1990) [28]. Conventional soil conservation strategies involve encouraging farmers to adopt improved farming systems and crop production techniques, but economic factors like food security, land, labor, capital constraints, tenure problems, and risk perceptions need to be considered (Barbier and Burgess, 1992) [18].

Soil degradation and erosion, exacerbated by climate change, pose a significant threat to the productivity and sustainability of smallholder farms (Climate Change, 2022). This can lead to food shortages, limited access to nutritious food, and heightened food insecurity. However, adopting conservation agriculture and sustainable land management practices can mitigate these issues. Effective strategies include reduced tillage, cover cropping, agroforestry, and crop rotation (Sithole and Olorunfemi, 2024) [109]. Environmentally friendly farming requires attention to environmental, social, and economic issues (Funes *et al*., 2008). Our understanding of sustainability continues to evolve, reflecting contemporary concerns, perspectives, and values (Pretty *et al*., 2002). By embracing sustainable practices, smallholder farmers can preserve soil fertility, minimize degradation, and ensure long-term agricultural productivity and sustainability.

Nature-based solutions in smallholder agriculture incorporate ecological principles and biodiversity conservation, which can promote food security, reduce costs, and open niche markets. Ecological and climate-smart agricultural practices are crucial for driving sustainable agricultural transformation in Africa. However, public investment in this critical area remains insufficient (Kamara *et al*., 2019) [62], highlighting a pressing need for greater commitment and resources. Promoting climate-resilient agricultural practices can aid smallholder farmers in adapting to climate change (IPCC, 2021). To strengthen smallholders' resilience, policies should focus on interventions that balance economic growth with environmental sustainability, tailored to the unique needs of diverse farmers and household types. Providing timely and accurate climate information can support informed decision-making among farmers (Hansen *et al*., 2019) [45]. Key strategies include promoting climate-resilient agricultural practices, investing in water management infrastructure, providing timely and accurate climate information, and implementing social protection measures. Investing in water management infrastructure is vital for agricultural productivity and climate resilience (World Bank, 2016).

Conclusion

Sustainable agricultural transformation is not just important; it is imperative for the future of Sub-Saharan Africa. It is the driving force behind economic growth, social justice, and environmental resilience. To revolutionize Africa's agricultural landscape, we must delve deeply into the socio-cultural, economic, and environmental dimensions of smallholder farmers. This transformation demands collaborative efforts across sectors, which are essential for generating insights and catalyzing change. By integrating indigenous knowledge systems, considering gender dynamics, and addressing the pressing issue of climate change, we can unlock the immense potential of smallholder farmers, boost productivity, and secure food supplies. These measures are not optional; they are essential for Africa's agricultural competitiveness and economic prosperity. Empowering smallholder farmers is the linchpin of agricultural transformation, necessitating a profound understanding of local contexts and the promotion of sustainable practices to enhance environmental sustainability and resilience. By prioritizing holistic approaches that empower smallholder farmers, the region can achieve food security, rural development, and climate resilience, ultimately paving the way for a prosperous and equitable future. The time to act is now. Collective action will shape a more sustainable future for African agriculture and its people.

References

1. Abraham M, Pingali P. Transforming Smallholder Agriculture to Achieve the SDGs. In: Paloma SG, Riesgo L, Louhichi K, editors. The Role of Smallholder Farms in Food and Nutrition Security. Cham: Springer; 2020. p. 151-65. doi:10.1007/978-3-030-42148-9_9.
2. Abrar-ul-haq M, Jali MRM, Islam GMN. Empowering Rural Women in Pakistan: Empirical Evidence from Southern Punjab. Qual Quant. 2017;51(4):1777-87. doi:10.1007/s11135-016-0365-7.
3. Adebayo JA, Worth SH. Profile of Women in African Agriculture and Access to Extension Services. Soc Sci Humanit Open. 2024;9:100790. doi:10.1016/j.ssaho.2023.100790.
4. Andersen ML. Thinking about Women: Sociological Perspectives on Sex and Gender. 7th ed. Boston: Allyn and Bacon; 2006.
5. Andersson E, Brogaard S, Olsson L. The political ecology of land degradation. Annu Rev Environ Resour. 2011;36:295-319. doi:10.1146/annurev-environ-033110-092827.
6. Andersson RH, Cothran B, Kekki S. Traditional Indigenous Knowledge and Nature Protection. Cult Concepts. 2021;1.
7. Annappa NN, Kasturappa BNG, Sn UK, Murthy RK. Climate Change's Threat to Agriculture: Impacts, Challenges and Strategies for a Sustainable Future. In: Climate Change and Agriculture. Delhi: AkiNik; 2023.
8. AO. New FAO report highlights urgent need to restore Africa's degraded landscape. Clim Environ. 2021 Sep 29.
9. Archard F, Eva HD, Stibig H, *et al*. Determination of Deforestation Rates of the World's Humid Tropical Forests. Science. 2002;297:999-1002.
10. Aryal JP, Marenya P. Understanding Climate-Risk Coping Strategies among Farm Households: Evidence from Five Countries in Eastern and Southern Africa. Sci Total Environ. 2021;769:145236.
11. Assan N. Socio-Cultural, Economic, and Environmental Implications for Innovation in Sustainable Food in Africa. Front Sustain Food Syst. 2023;7:1192422. doi:10.3389/fsufs.2023.1192422.
12. Axon S. The Socio-Cultural Dimensions of Community-Based Sustainability: Implications for Transformational Change. J Clean Prod. 2020:121933.
13. Ayoade AR, Adewole WA, Adetunbi SI, Dairo PO. Effectiveness of the use of Indigenous Knowledge in Livestock Production in Oriire Local Government Area of Oyo State. Int J Soc Sci Humanit Res. 2020;3(12):1-17.
14. Balogun T. Data management of digitized indigenous knowledge system in repositories. Inf Dev. 2023:1-13. doi:02666669231186777.
15. Balogun T, Kalusopa T. A framework for digital preservation of Indigenous knowledge system (IKS) in repositories in South Africa. Rec Manag J. 2021;31(2):176-96.
16. Barakabitze AA, Fue KG, Sanga CA. The use of participatory approaches in developing ICT-based systems for disseminating agricultural knowledge and information for farmers in developing countries: The case of Tanzania. Electron J Inf Syst Dev Ctries. 2017;78:1-23.
17. Barbier EB. The economic determinants of land degradation in developing countries. Philos Trans R Soc B. 1997;352:891-9.
18. Barbier EB, Burgess JC. Malawi Land Degradation in Agriculture. Environ Dep Work Pap No. 1992-37. Washington: World Bank; 1992.
19. Barbier EB, Hochard JP. Land degradation and poverty. Nat Sustain. 2018;1:623-31. doi:10.1038/s41893-018-0155-4.
20. Bhasin K. What is Patriarchy? New Delhi: Kali for Women; 1993.
21. Birthal PS, *et al*. Vertical coordination in high-value food commodities: implications for smallholders. MTID Discuss Pap No. 85. Washington: IFPRI; 2005.
22. Biswas A, Sarkar S, Das S, *et al*. Water scarcity: A global hindrance to sustainable development and agricultural production - A critical review of the impacts and adaptation strategies. Camb Prisms Water. 2025;3:e4. doi:10.1017/wat.2024.16.
23. Bol GK, van Niekerk D. African Indigenous Understanding of Climate Change and Disaster Risk Nexus. In: Geohazards and Disaster Risk Reduction. Springer; 2023. p. 269-89.
24. Brubacher LJ, *et al*. Climate change, biodiversity loss, and Indigenous Peoples' health and wellbeing: A systematic umbrella review. PLOS Glob Public Health. 2024;4(3):e0002995. doi:10.1371/journal.pgph.0002995.
25. Bugri JT. The dynamics of tenure security, agricultural production and environmental degradation in Africa: Evidence from stakeholders in north-east Ghana. Land Use Policy. 2008;25:271-85.
26. Byerlee D, *et al*. Strategies for technical change in small-farm agriculture, with particular reference to sub-Saharan Africa. In: Russel N, Dowswell C, editors. Policy Options for Agricultural Development in sub-Saharan Africa. VA: CASIN; 1992. p. 21-52.
27. Chikanda A. Environmental Degradation in Sub-Saharan Africa. In: Luginaah IN, Yanful EK, editors. Environment and Health in Sub-Saharan Africa. Springer; 2009. p. 81-96. doi:10.1007/978-1-4020-9382-1_6.
28. Colby ME. Environmental Management in Development: The Evolution of Paradigms. World Bank Discuss Pap 80. Washington: World Bank; 1990.
29. Curry GN, *et al*. Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world. J Rural Stud. 2021;88:422-31. doi:10.1016/j.jrurstud.2021.07.02.
30. Desai N, Krishnaraj M. An overview of the status of women in India. In: Mohanty M, editor. Class, Caste, Gender. New Delhi: Sage; 2004.
31. Dhillon R, Moncur Q. Small-scale farming: A review of challenges and potential opportunities offered by technological advancements. Sustainability. 2023;15:15478. doi:10.3390/SU152115478.
32. Dixon RK, Smith J, Guill S. Life on the edge: Vulnerability and adaptation of African ecosystems to global climate change. Mitig Adapt Strateg Glob Chang. 2003;8(2):93-113.
33. Dorward A, Fan S, Kydd J, *et al*. Rethinking agricultural policies for pro-poor growth. Nat Resour Perspect.

2004;94:1-4.
34. Drissi S. Indigenous peoples and the nature they protect. UNEP. 2023. [Accessed 2024 Mar 11].
35. Dzanku FM, Jirström M, Marstorp H. Yield gap-based poverty gaps in rural Sub-Saharan Africa. World Dev. 2015;67:336-62.
36. Ellis F, Freeman HA. Rural livelihoods and poverty reduction strategies in four African countries. J Dev Stud. 2004;40(4):1-30.
37. FAO. The State of Food and Agriculture 2020: Overcoming Water Challenges in Agriculture. Rome: FAO; 2020.
38. FAO, IFAD, UNICEF, *et al*. The State of Food Security and Nutrition in the World 2019. Rome: FAO; 2019.
39. Ford JD, *et al*. Including Indigenous Knowledge and Experience in IPCC Assessment Reports. Nat Clim Chang. 2016;6(4):349-53.
40. Giller KE, *et al*. Small farms and development in sub-Saharan Africa: Farming for food, for income or for lack of better options? Food Secur. 2021;13:1431-54.
41. Glopan. Future Food Systems: for People, Our Planet and Prosperity. London: Global Panel; 2020.
42. Gorjestani N. Indigenous Knowledge for Development: Opportunities and Challenges. Washington: World Bank; 2000.
43. Gray L, Morant P. Reconciling Indigenous Knowledge with Scientific Assessment of Soil Fertility Changes in Southwestern Burkino Faso. Geoderma. 2003;111:425-37.
44. Hainzer K, O'Mullan C, Brown P. The use of local knowledge in agricultural extension: A systematic review of the literature. J Agric Ext Rural Dev. 2022;14(1):1-12. doi:10.5897/JAERD2021.1295.
45. Hansen J, *et al*. Scaling climate services to enable effective adaptation action. Rotterdam; 2019. p. 1-23.
46. Hébert K. Biodiversity change is more than the sum of its parts. Nat Rev Biodivers. 2025. doi:10.1038/s44358-025-00048-7.
47. Hensher DA, Greene WH. The Mixed Logit model: The state of practice. Transportation. 2003;30:133-76.
48. Hernando A, Nikita E, Rehren T. CHAP-Gender and Heritage. In: Encycl Archaeol. 2nd ed. Oxford: Academic; 2024. doi:10.1016/B978-0-323-90799-6.00051-3.
49. HLPE. Investing in smallholder agriculture for food security. Rome: CFS; 2013.
50. IDA. Agriculture: An Engine for Growth and Poverty Reduction. 2009. [Accessed 2012 Oct 20].
51. Ingrao C, *et al*. Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. Heliyon. 2023;9:e18507. doi:10.1016/j.heliyon.2023.e18507.
52. IPCC. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Cambridge: CUP; 2014.
53. IPCC. Climate Change 2021: The Physical Science Basis. Cambridge: CUP; 2021. doi:10.1017/9781009157896.
54. IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. 2022.
55. Islam MM, *et al*. Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: Insights from coastal Bangladesh. Reg Environ Chang. 2014;14(1):281-94.
56. Jambwa P, *et al*. Ethnoveterinary remedies used in avian complementary medicine in selected communal areas in Zimbabwe. Planta Med. 2021;88(3/4):313-23.
57. Jayne TS, *et al*. Africa's changing farm size distribution patterns: The rise of medium-scale farms. Agric Econ. 2016;47(S1):197-214.
58. Jejeebhoy SJ, Sathar ZA. Women's autonomy in India and Pakistan: The influence of religion and region. Popul Dev Rev. 2001;27(4):687-712.
59. Ji C, *et al*. Dynamic Integrated Ecological Assessment along the Corridor of the Sichuan-Tibet Railway. Land. 2024;13(6):857. doi:10.3390/land13060857.
60. Jiri O, *et al*. Seasonal climate prediction and adaptation using indigenous knowledge systems in agriculture systems in Southern Africa: A review. J Agric Sci. 2016;8(5):156.
61. Kabeer N. Reflections on the measurement of women's empowerment. In: Discussing Women's Empowerment. Stockholm: Sida; 2001.
62. Kamara A, *et al*. The relevance of smallholder farming to African agricultural growth and development. Afr J Food Agric Nutr Dev. 2019;19:14043-65. doi:10.18697/ajfand.84.blfb1010.
63. Kapari M, *et al*. Contribution of smallholder farmers to food security and opportunities for resilient farming systems. Front Sustain Food Syst. 2023;7:1149854.
64. Kavu S, Kajongwe C, Ebhuoma EE. Climate change experts' perspective on the role of indigenous knowledge systems in climate change adaptation in Southern Africa. In: Indigenous Knowledge and Climate Governance. Springer; 2022. p. 67-80.
65. Khan FU, *et al*. Constraints to agricultural finance in underdeveloped and developing countries: A systematic literature review. Int J Agric Sustain. 2024;22(1). doi:10.1080/14735903.2024.2329388.
66. Kugara SL, *et al*. The role of Indigenous Knowledge Systems (IKS) in climate change. In: Handbook of Research on Protecting and Managing Global Indigenous Knowledge Systems. IGI; 2022. p. 1-23.
67. Kurukulasuriya P, *et al*. Will African Agriculture Survive Climate Change? World Bank Econ Rev. 2006;20(3):367-88.
68. Kydd J, *et al*. Agricultural development and pro-poor economic growth in sub-Sahara Africa: potential and policy. ADU Work Pap 02/04. Wye: Imperial Coll; 2002.
69. Lwoga E, Ngulube P, Stilwell C. Managing Indigenous Knowledge for Sustainable Agricultural Development in Developing Countries. Int Inf Libr Rev. 2010;42:174-85.
70. Makondo C, Thomas DS. Climate Change Adaptation: Linking Indigenous Knowledge with Western Science for Effective Adaptation. Environ Sci Policy. 2018;88:83-91.
71. Malapane OL, Chanza N, Musakwa W. Transmission of indigenous knowledge systems under changing landscapes within the vhavenda community, South Africa. Environ Sci Policy. 2024;161:103861. doi:10.1016/j.envsci.2024.103861.
72. Maroyi A. Use of ethnoveterinary medicine by small-scale farmers to treat livestock diseases. Int J Sci Technol Res. 2021;10(7):32-40.
73. Martial T, *et al*. Women's role in supporting the sustainability of smallholder coffee plantations in North Sumatra, Indonesia. Int J Adv Appl Sci. 2025;12(1):141-53.

74. Mason K, Smith HL. Husbands' versus wives' fertility goals and use of contraception. Demography. 2000;37(3):299-311.
75. Mathieu S, *et al*. The Role of Unemployment, Financial Hardship, and Economic Recession on Suicidal Behaviors and Interventions to Mitigate Their Impact. Front Public Health. 2022;10:907052. doi:10.3389/fpubh.2022.907052.
76. Mazzocchi F. Western science and traditional knowledge. EMBO Rep. 2006;7(5):463-6.
77. Mbow C, *et al*. Food Security. In: Climate Change and Land. IPCC; 2019.
78. Melash AA, *et al*. Indigenous agricultural knowledge: A neglected human-based resource for sustainable crop protection and production. Heliyon. 2023;9(1):e12978.
79. Montanarella L, Scholes R, Brainich A. The IPBES Assessment Report on Land Degradation and Restoration. IPBES; 2018. doi:10.5281/zenodo.3237392.
80. Moyo BHZ. Indigenous knowledge-based farming practices. Scott Geogr J. 2009;125(3-4):353-60.
81. Munyangeyo T. Socio-Cultural Shifts in The Representation of Gender (In)Equality in Africa. Int J Afr Soc Cult Tradit. 2023;11(2):61-76.
82. Muzari W, Gatsi W, Muvhunzi S. The impacts of technology adoption on smallholder agricultural productivity in sub-Saharan Africa. J Sustain Dev. 2012;5(8):69-83. doi:10.5539/jsd.v5n8p69.
83. Nara BB, Lengoiboni M, Zevenbergen J. Assessing customary land rights and tenure security variations of smallholder farmers in northwest Ghana. Land Use Policy. 2021;104:105352. doi:10.1016/j.landusepol.2021.105352.
84. Nassary EK. Exploring the role of nature-based solutions and emerging technologies in advancing circular and sustainable agriculture. Clean Circ Bioecon. 2025;10:100142.
85. Nyambo P, *et al*. Sub-Saharan Africa Smallholder Farmers Agricultural Productivity: Risks and Challenges. In: Mupambwa HA, *et al*., editors. Food Security for African Smallholder Farmers. Springer; 2022. doi:10.1007/978-981-16-6771-8_3.
86. Nyong A, Adesina F, Elasha BO. The Value of Indigenous Knowledge in Climate Change Mitigation and Adaptation Strategies in the African Sahel. Mitig Adapt Strateg Glob Chang. 2007;12(5):787-97.
87. Ogar E, Pecl G, Mustonen T. Science must embrace traditional and indigenous knowledge to solve our biodiversity crisis. One Earth. 2020;3(2):162-5.
88. Olanipekun IO, Olasehinde-Williams GO, Alao RO. Agriculture and environmental degradation in Africa. Sci Total Environ. 2019;692:60-7. doi:10.1016/j.scitotenv.2019.07.129.
89. Osumanu IK. Climate change adaptation and agricultural livelihoods of smallholder farmers. In: The Routledge Handbook on Livelihoods in the Global South. London: Routledge; 2022. p. 481-9.
90. Otekunrin OA, *et al*. Three decades of fighting against hunger in Africa. World Nutr. 2020;11:86-111.
91. Owino V, *et al*. The impact of climate change on food systems, diet quality, nutrition, and health outcomes. Front Clim. 2022. doi:10.3389/fclim.2022.907052.
92. Petrovic B, Csambalik L. Enhancing Precision Agriculture for Climate Change Mitigation in Visegrad Countries. Land. 2025;14:399. doi:10.3390/land14020399.
93. Pulerwitz J, Gortmaker SL, DeJong W. Measuring sexual relationship power in HIV/STD research. Sex Roles. 2000;42(7/8):637-60.
94. Qwabe Q. Indigenous knowledge is a natural resource for rural farmers. Food Mzansi. 2020. [Accessed 2023 Feb 17].
95. Radcliffe C. The Sustainable Agriculture Learning Framework. Rural Ext Innov Syst J. 2017;13(2):41.
96. Radcliffe C, Parissi C. Understanding and preserving Indigenous agricultural knowledge. Glob Knowl Mem Commun. 2022:1-20.
97. Radcliffe C, *et al*. More than a political slogan: The value of Kastom in extension for sustainable agriculture. Rural Ext Innov Syst J. 2018;14(1):91-100.
98. Radcliffe C, Parissi C, Raman A. Valuing Indigenous Knowledge in the Highlands of Papua New Guinea. Aust J Environ Educ. 2016;32(3):243-59.
99. Radcliffe C, Raman A, Parissi C. Entwining indigenous knowledge and science knowledge for sustainable agricultural extension. J Agric Educ Ext. 2020. doi:10.1080/1389224X.2020.1828112.
100. Ravazzoli E, Valero DE. Social innovation: An instrument to achieve the sustainable development of communities. In: Leal Filho W, *et al*., editors. Sustain Cities Commun. Springer; 2020. doi:10.1007/978-3-319-71061-7_108-1.
101. Rosegrant WM, *et al*. Returns to investments in reducing postharvest food losses and increasing agricultural productivity growth. CGIAR Work Pap. 2015.
102. Rotmans J, *et al*. Multi- Inter- and Transdisciplinary Research Program into Transitions and System Innovations. Maastricht: Maastricht Univ; 2004.
103. Roudier P, *et al*. The impact of future climate change on West African crop yields. Glob Environ Chang. 2011;21(3):1073-83.
104. Ruiz Navajas A. Credit guarantee schemes: Conceptual frame. GTZ/FONDESIF Financ Syst Dev Proj. 2001.
105. Scholes RJ. Syndromes of dryland degradation in southern Africa. Afr J Range Forage Sci. 2009;26(3):113-25. doi:10.2989/AJRF.2009.26.3.2.947.
106. Sharma IP, Kanta C, Dwivedi T, Rani R. Indigenous agricultural practices: A supreme key to maintaining biodiversity. In: Goel R, *et al*., editors. Microbiol Adv High Alt Agro-Ecosyst Sustain. Springer; 2020. p. 91-112.
107. Shilomboleni H, *et al*. Scaling up innovations in smallholder agriculture. Agric Syst. 2019;175:58-65. doi:10.1016/j.agsy.2019.05.012.
108. Simon R, Hasan S. Patriarchy and Gender Inequality: A Comprehensive Analysis of Women's Empowerment in Contemporary India. Gend Issues. 2025;42:7. doi:10.1007/s12147-025-09351-1.
109. Sithole A, Olorunfemi OD. Sustainable Agricultural Practices in Sub-Saharan Africa. Sustainability. 2024;16(22):9766. doi:10.3390/su16229766.
110. Sithole PM. Use of indigenous knowledge systems in crop and livestock production. South Afr J Environ Educ. 2020;36:21-32. doi:10.4314/sajee.v36i1.3.
111. Smith H, Sharp K. Indigenous Climate Knowledge's. WIREs Clim Chang. 2012;3:467-76.
112. Speranza CI, *et al*. Indigenous Knowledge Related to Climate Variability and Change. Clim Change.

2010;100:295-315.
113. Stocking MA, Murnaghan N. A Handbook for the Field Assessment of Land Degradation. Routledge; 2001.
114. Swinnen JFM, Maertens M. Finance through food and commodity value chains in globalized. KFW Financ Sect Dev Symp. 2010.
115. Touch V, *et al*. Smallholder farmers' challenges and opportunities. J Environ Manage. 2024;370:122536. doi:10.1016/j.jenvman.2024.122536.
116. UNESCO. The United Nations World Water Development Report 2023. Paris: UNESCO; 2023.
117. USAID. Adoption of climate-smart agriculture in Africa. Washington: Integra LLC; 2016.
118. van Asseldonk M, *et al*. Policy incentives for smallholder adoption of climate-smart agricultural practices. Front Polit Sci. 2023. doi:10.3389/fpos.2023.XXXXX.
119. Vincent K, Cull T. Using Indicators to Assess Climate Change Vulnerabilities. Geogr Compass. 2014;8(1):1-12.
120. Wakweya RB. Challenges and prospects of adopting climate-smart agricultural practices. J Agric Food Res. 2023;14:100698. doi:10.1016/j.jafr.2023.100698.
121. Walby S. Towards a theory of patriarchy. Gend Stud. UK: Blackwell; 2002.
122. Warren R, *et al*. The implications of the United Nations Paris Agreement on climate change for globally significant biodiversity areas. Clim Change. 2018;147:395-409. doi:10.1007/s10584-018-2158-6.
123. World Bank. Engendering development. Oxford: OUP; 2001a.
124. World Bank. World development report 2001. New York: OUP; 2001b.
125. World Bank. World Bank investments in building the capacity of rural producer organizations. Washington: World Bank; 2012.
126. World Bank. Climate information services providers in Kenya. Washington: World Bank; 2016.
127. Zhang X, *et al*. Global food production could be at risk due to water scarcity under climate change. Environ Res Lett. 2021;16(3):034015. doi:10.1088/1748-9326/abd8ef.