

AGROECOLOGY AND IRRIGATION IN AFRICA: SYNERGIES FOR SUSTAINABLE AND CLIMATE-RESILIENT FOOD SYSTEMS

AGROÉCOLOGIE ET IRRIGATION EN AFRIQUE : SYNERGIES ENTRE DES SYSTÈMES ALIMENTAIRES DURABLES ET RESISTANTS AU CLIMAT

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ABSTRACT

Agroecology is increasingly recognised as a pathway towards sustainable, resilient, and equitable food systems. Across much of sub-Saharan Africa, however, agroecological transitions are constrained by highly variable rainfall, recurrent droughts, and limited water availability. Smallholder farming systems are predominantly rainfed, resulting in unstable yields, seasonal food shortages, and limited opportunities for crop diversification and market participation. Simultaneously, climate change is intensifying rainfall variability and increasing the frequency of extreme weather events, further threatening agricultural productivity and rural livelihoods. This paper explores the synergies between agroecology and irrigation, arguing that appropriate water management interventions can serve as critical enablers of agroecological development and are not viewed as separate or competing approaches.

The characteristics and challenges of sub-Saharan African farming systems are reviewed and how agroecological principles can improve resource-use efficiency, biodiversity conservation, soil health, and climate resilience is examined. Attention is given to the role of water as a limiting factor in agroecological production systems. Nature-based solutions such as rainwater harvesting, conservation agriculture, wetland restoration, and soil moisture conservation are discussed alongside technological innovations including low-cost drip irrigation, solar-powered pumping systems, and digital advisory tools. Such interventions can improve water productivity while supporting ecological sustainability and reducing vulnerability to climatic shocks.

South African case studies from the Free State and Western Cape provinces illustrate how supplementary irrigation and rainwater harvesting have contributed to improved crop productivity, enhanced water-use efficiency, increased dietary diversity, and greater resilience to climate variability. The paper further examines the alignment of agroecology-irrigation integration with the African Union's Malabo Declaration and Agenda 2063. It concludes that combining agroecological principles with efficient and context-appropriate irrigation technologies offers a practical pathway for achieving sustainable agricultural intensification, improved food and nutrition security, and enhanced resilience of African agri-food systems under changing climatic conditions.

Keywords: Agroecology, supplementary irrigation, rainwater harvesting, climate resilience, food security, Africa.

RESUME

L'agroécologie apparaît de plus en plus clairement comme une voie vers des systèmes alimentaires durables, résistants et équitables. Cependant, à travers la plus grande partie de l'Afrique subsaharienne, les transitions agroécologiques sont freinées par une pluviométrie très variable, des sécheresses

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récurrentes et une disponibilité limitée en eau. Les systèmes agricoles des petits exploitants dépendent largement sur l'agriculture pluviale, ce qui donne lieu aux rendements instables, aux pénuries alimentaires saisonnières et aux possibilités limitées de diversification des cultures et à l'accès aux marchés. Parallèlement, le changement climatique intensifie la variabilité des précipitations et augmente la fréquence des phénomènes météorologiques extrêmes, menaçant encore davantage la productivité agricole et les moyens de subsistance des populations rurales. Cet article explore les synergies existantes entre l'agroécologie et l'irrigation, en soutenant que des interventions appropriées en matière de gestion de l'eau peuvent agir comme des catalyseurs essentiels du développement agroécologique et ne doivent pas être considérées comme des approches distinctes ou concurrentes.

L'étude passe en revue les caractéristiques et les défis des systèmes agricoles d'Afrique subsaharienne, et examine la manière dont les principes agroécologiques peuvent améliorer l'efficacité de l'utilisation des ressources, la conservation de la biodiversité, la santé des sols et la résistance climatique. Une attention particulière est accordée au rôle joué par l'eau en tant que facteur limitant les systèmes de production agroécologiques. Les solutions fondées sur la nature, telles que la collecte des eaux de pluie, l'agriculture de conservation, la restauration des zones humides et la préservation de l'humidité des sols, sont abordées parallèlement à des innovations technologiques, notamment l'irrigation goutte-à-goutte à faible coût, les systèmes de pompage à énergie solaire et les outils numériques consultatifs. De telles interventions peuvent améliorer la productivité de l'eau tout en favorisant la durabilité écologique et en réduisant la vulnérabilité aux chocs climatiques.

Des études de cas sud-africaines menées dans les provinces de l'État libre et du Cap-Occidental illustrent la manière dont l'irrigation d'appoint et la collecte des eaux de pluie ont contribué à améliorer la productivité agricole, à optimiser l'efficacité de l'utilisation de l'eau, à accroître la diversité alimentaire et à renforcer la résistance face à la variabilité climatique. En outre, l'article examine l'adéquation de l'intégration de l'agroécologie et de l'irrigation dans la Déclaration de Malabo et l'Agenda 2063 de l'Union africaine. En conclusion, il est constaté que l'association des principes agroécologiques avec des technologies d'irrigation efficaces et adaptées au contexte offre une voie concrète pour parvenir à une intensification agricole durable, à une meilleure sécurité alimentaire et nutritionnelle, ainsi qu'à une résistance accrue des systèmes agroalimentaires africains face à l'évolution des conditions climatiques.

Mots-clés : Agroécologie; Irrigation d'appoint; Collecte des eaux de pluie; Résistance au climat; Sécurité alimentaire; Afrique.

INTRODUCTION

Agriculture remains the primary livelihood source for millions of people across sub-Saharan Africa, yet agricultural productivity continues to be constrained by rainfall variability, recurrent droughts, land degradation, and limited access to irrigation infrastructure. More than 90% of cultivated land in many African countries remains dependent on rainfall, exposing farming households to substantial production risks. Climate change is expected to exacerbate these challenges through increased temperatures, shifting rainfall patterns, and greater frequency of extreme weather events. Thus Agroecology has emerged as a promising framework for addressing these challenges through the application of ecological principles to agri-food systems. Agroecological approaches seek to enhance biodiversity, improve soil health, strengthen ecosystem services, and reduce dependence on external inputs while promoting social equity and food sovereignty.

Agroecology is a holistic and integrated approach to agri-food systems that combines ecological science, social principles, and cultural knowledge to design and manage sustainable, resilient, and equitable food systems. Its foundation is traditional and local knowledge while applying scientific innovation to optimize interactions among plants, animals, humans, and the environment. By minimizing dependence on external inputs and strengthening ecological processes, agroecology encompasses practices such as organic, regenerative, and conservation agriculture, permaculture, diversified cropping systems, and integrated crop-livestock systems. Beyond production, it also represents a social movement and policy framework that promotes food sovereignty, equity, and community empowerment (FAO, 2018; HPLE, 2019).

Despite its potential, agroecological production remains vulnerable in semi-arid environments where water availability frequently limits crop growth and productivity. The integration of irrigation and water management strategies into agroecological systems therefore offers important opportunities to enhance resilience, improve productivity, and support sustainable intensification.

This paper examines the relationship between agroecology and irrigation within African agricultural systems and presents examples from South Africa demonstrating how supplementary irrigation and rainwater harvesting can support agroecological development.

SUB-SAHARAN AFRICAN FARMING SYSTEMS

Farming systems across sub-Saharan Africa are predominantly driven by smallholders operating diverse, rain-fed operations that have mixed production of both crops and livestock. These systems range from cereal-root crop cultivation in humid zones to pastoralism in arid areas, heavily adapting to local climates and soil conditions by utilizing intercropping to optimize natural resources (Hall et al., 2001). Mixed farming in sub-Saharan Africa enhances land use, soil fertility, and environmental sustainability through crop-livestock integration, intercropping, and nutrient cycling. Challenges include land competition, disease, limited feed, policy constraints, and low technology adoption. Research should focus on improving productivity, disease control, and policy support to promote sustainable intensification and address food security (Mohammed-Saleem, 1995).

Smallholder farmers control over 80% of the agricultural workforce in sub-Saharan Africa, serving as the primary backbone of the region's food security and rural livelihoods. These systems are categorised into major distinct zones based on agro-ecological characteristics and the types of farming systems – a Maize mixed system (maize, legumes, cattle rearing), cereal-root mixed cropping (cassava, yams); tree crops (e.g. cocoa, coffee, oil & date palm) and a agropastoral or pastoral systems across the arid and semi-arid drylands (with millets, sorghum, livestock herding) (Hall et al., 2001).

The most productive areas are those farmed under some type of irrigation scheme, although this is a small percentage of the arable land. Irrigation water is mostly derived from overland flow and storage of rainwater in small dams, which families are very dependent upon. In contrast to the rainfed areas, crop failures in these areas are minimum, but the farmer's income is subjected to water supply or scarcity dependent on the sporadic rainfall. Thus, livelihoods are vulnerable to water shortages, as well as scheme management, and fluctuating prices of inputs and outputs. Multiple schemes are no longer producing to their full potential due to aging of the infrastructure and excessive institutional documentation as well as local limiting factors or distortions. However, with improved support from extension and non-governmental organisations (NGOs) with the correct skills, water scarcity could be resolved to drastically boost agricultural production (Malatsi et al., 2025).

Therefore, the core challenges for the farming systems in these areas include the variability of the climate causing increased vulnerability, land degradation (including due to soil erosion, overgrazing), infrastructure deficits due to lack of maintenance and aging both on farm and limited access to markets due to poor roads and storage facilities (Akaribo et al., 2026). The small-scale irrigation areas across southern Africa are particularly affected by severe operational, institutional, and environmental bottlenecks that lead to widespread system collapse and thus under-utilised land. This deterioration is despite significant public funding, resulting in many community plots being completely abandoned and unproductive, due to both technical and institutional challenges. Some of these challenges include infrastructure decay, weak governance structures, land tenure insecurity, capacity / knowledge gaps, as well as severe environmental stresses and economic constraints (Machethe et al., 2025).

Some of these challenges can be addressed by using the principles of Agroecology such as leveraging synergies and local governance structures for the rehabilitation reinforced by economic diversification and increasing biodiversity of the irrigated farming system. Such improvements can be supported by good participation and connectivity between the consumer and producers by utilizing the local traditional knowledge (especially of the elderly) in co-creation of farming technical knowledge to support the local social and cultural diets and family structures. Agroecology can assist in rebuilding southern Africa's

failing small-scale irrigation schemes by shifting the focus away from high-cost engineering fixes toward low-input, natural processes that reduce water demand and build local community autonomy. Instead of treating irrigation purely as a plumbing problem, an agroecological approach redesigns the entire farming system to work as a self-sustaining circular ecosystem with connections between the growers-irrigators and the consumers.

AGROECOLOGY AND WATER MANAGEMENT IN AFRICAN FARMING SYSTEMS

Water management is vital for all farming systems, so also in agroecology systems that are based on principles that optimise ecological interactions within the whole agricultural landscape. Important principles include diversification, nutrient cycling, biological pest regulation, soil health improvement, and efficient resource use. In African smallholder systems, agroecological practices often incorporate intercropping, agroforestry, indigenous crops and livestock breeds, conservation agriculture, integrated crop-livestock systems, and the use of indigenous knowledge. Water availability remains a central determinant of the success of these practices. In many semi-arid regions, annual rainfall may be sufficient to support crop production, but poor temporal distribution often results in prolonged dry spells during critical crop growth stages (Madamombe et al., 2025). Consequently, crop failures frequently occur despite apparently adequate seasonal rainfall totals. This necessitates the need for supplementary irrigation. Therefore, the integration of irrigation into agroecological systems can reduce these risks by stabilising production, enabling diversification, and extending growing seasons. Supplementary irrigation during critical growth stages can significantly increase crop yields while using relatively small quantities of water to alleviate water stress.

Water management within agroecological systems extends beyond the provision of irrigation water and includes the stewardship of the entire hydrological cycle within the broader farming landscape. Healthy soils function as natural reservoirs that store rainfall and gradually release moisture to crops during dry periods. Agroecological practices such as the incorporation of organic matter, use of cover crops, agroforestry, contour farming, and reduced tillage improve soil structure and increase infiltration rates while reducing runoff and erosion. In addition, diversified farming systems create multiple vegetation layers that moderate soil temperatures and reduce evaporative losses, bringing changes to the water balance. These functions are particularly important in African dryland environments where rainfall is often intense, short in duration, and followed by extended dry spells. By increasing the capacity of soils and landscapes to capture and retain water, agroecological management can significantly enhance rainfall-use efficiency and reduce dependence on external water sources. This ecosystem-based approach to water management strengthens both agricultural productivity and resilience while simultaneously supporting biodiversity conservation and long-term environmental sustainability.

SYNERGIES BETWEEN AGROECOLOGY AND IRRIGATION

Irrigation and agroecology are often viewed as separate development pathways. However, significant synergies exist between these approaches, so that agroecology can be introduced to promote food security as a viable intervention in failing irrigation schemes. Many of the sub-Saharan agri-food systems in semi-arid areas are based on rain-fed maize and legume (Melese et al., 2025) with some foraging to collect wild plants or herbs (Herd-Hoare & Shackleton, 2022). Therefore, access to reliable water supplies would enable farmers to diversify beyond staple cereal production and cultivate vegetables, fruits, fodder crops, and legumes. Increased diversity improves household food nutrition, strengthens ecological resilience, and contributes to enhanced soil fertility through improved nutrient cycling.

Agroecological systems can also improve irrigation performance. Increased soil organic matter enhances infiltration, water-holding capacity, and root development, thereby improving water-use efficiency. Mulching, cover cropping, conservation tillage, and agroforestry reduce evaporation losses and increase the effectiveness of limited water resources (Ramos et al., 2024).

The integration of crop and livestock enterprises plays a pivotal role in strengthening agricultural system resilience. This synergistic approach creates a closed-loop system where the waste product of one enterprise becomes a valuable input for the other (Serakan et al., 2021). By recycling nutrients on-farm,

producers significantly lower their dependency on external synthetic fertilisers, which in turn reduces operational costs and mitigates environmental degradation. Furthermore, maintaining multiple distinct revenue streams from both plant and animal products buffers the farm against volatile market prices and unpredictable climate events. Ultimately, this ecological and economic diversification transforms vulnerable monoculture operations into robust, self-sustaining ecosystems capable of absorbing external shocks (Kamakaula, 2025).

Additional synergies emerge when irrigation systems are designed and managed according to agroecological principles. Small-scale, farmer-managed irrigation technologies can support decentralized food production systems that are adapted to local environmental and socio-economic conditions. Reliable access to water enables farmers to establish agroforestry systems, cultivate nutrient-rich indigenous vegetables, maintain cover crops during dry periods, and integrate livestock more effectively into mixed farming systems. Irrigation also facilitates year-round production, creating opportunities for improved household nutrition, income diversification, and participation in local markets. Importantly, agroecological principles help ensure that irrigation development does not result in unsustainable water extraction or environmental degradation. By emphasizing efficient water use, watershed protection, soil health restoration, and community participation in water governance, agroecology provides a framework through which irrigation investments can contribute simultaneously to productivity, environmental sustainability, and social equity. The combination of ecological management and appropriate irrigation technologies, therefore, offers a practical pathway for climate-smart agricultural development across diverse African farming systems.

SOUTH AFRICAN CASE STUDIES

In-field Rainwater Harvesting in the Free State

In-field Rainwater Harvesting (IRWH) is an agronomic water-management technique designed to minimize surface runoff and maximize soil water storage by capturing rainfall directly where it falls on the cultivated land (Hensley et al., 2000). The effectiveness of in-field rainwater harvesting techniques for smallholder crop production on marginal soils has been shown by research conducted by the Agricultural Research Council in the Free State. Runoff generated from compacted catchment strips is directed into adjacent cropped areas where water infiltrates and becomes available for plant growth. Studies have shown substantial increases in maize and sunflower yields compared with conventional tillage systems, particularly during below-average rainfall seasons (Walker et al., 2005). This technology has improved rainfall-use efficiency while reducing vulnerability to drought.

Indigenous Water Harvesting

Indigenous rainwater harvesting and conservation practices have been used for many years around the semi-arid areas of South Africa (Denison & Wotshela, 2009). They are usually the result of accumulated indigenous knowledge, practices and traditions which have evolved over many generations of experimentation and adaptation in a specific location. They range from the combination of indigenous, indigenised (as an adaptation of local and external influences) and others that are essentially contemporary-scientific methods. There are practices that have demonstrated the value of rainwater harvesting and conservation across the range of socio-economic and cultural spectrum of South Africa, inclusive of both resource-poor farmers and fully-fledged commercial farmers. There are a diverse range of practices, ranging from large-scale systems like 'saaidamme' (diverting flood water to distant fields) to micro-catchments, with some indigenous and others influenced by external factors. The indigenous knowledge is dynamic and has been evolving through internal innovation and external contact, thus contributing to developing sustainable practices by building to improve water harvesting efficiency and relevance for development, especially for resource-poor communities. Some innovations include homestead ponds, ploughs, stone terracing, diversion of water for both agricultural and household use.

Conservation Agriculture and Water Productivity

Conservation agriculture (CA) is a sustainable farming system that protects soil from degradation, improves biodiversity, and optimizes crop yields (FAO, 2022). It is built on three core, interconnected principles. Firstly, Minimum Soil Disturbance by avoiding traditional ploughing and tilling; the seeds are planted directly into the ground to preserve soil structure and retain moisture. Secondly, Permanent Soil Cover by keeping the soil surface covered with crop residues or cover crops to prevent erosion and to suppress weed growth. Thirdly, Crop Diversification by rotating different crops to break pest cycles, replenish soil nutrients, and improve biodiversity, usually with at least one legume included for nitrogen fixation. These three core principles are also part of agroecology and so these farmers have seen the need to make a change from the traditional conventional full ploughing systems.

Conservation agriculture initiatives in South Africa have demonstrated the importance of maintaining soil cover and reducing soil disturbance. These methods have been adopted by many of the rain-fed grain farmers in Free State and Western Cape areas (von Loeper & Strauss, 2015). Improved soil structure and increased organic matter content have enhanced infiltration rates, reduced runoff and evaporation, while retaining soil moisture, thus reducing irrigation requirements while maintaining crop productivity. Another benefit is improved soil health due to increased organic matter and a thriving ecosystem for microbes and earthworms. In addition, operational costs are lower due to less fuel and labour being used for heavy machinery although other value chain constraints may exist (von Loeper et al., 2019). These examples highlight the complementary relationship between agroecological soil management and efficient water use, showing that they can work together to reduce risks and increase sustainability of farming systems.

TECHNOLOGICAL AND NATURE-BASED INNOVATIONS

Nature-based solutions (NbS) play a central role in agroecological water management. These include in-field rainwater harvesting, contour bunds, grassed waterways, vegetative barriers, wetland restoration, and small earth dams to address water crises such as flood management, groundwater replenishment, environmental and land degradation, and agroecology transformations (Dey & Biswas 2024). NbS play a central role in agroecological water management by shifting the agricultural paradigm away from rigid, human-built engineering toward decentralized biological infrastructure that supports biodiversity (Rey et al., 2026). Rather than relying on energy-intensive irrigation and artificial drainage networks, NbS utilize and mimic natural ecological processes to capture, filter, and store water directly within the farming landscape while offering adaptive strategies with mixed ecological, social, and economic benefits (Tarolli et al., 2026). This systemic integration significantly buffers agricultural systems against climate-induced disruptions, such as prolonged droughts and flash flooding, while preserving the surrounding ecosystem's regenerative capacity. Ultimately, managing water through an agroecological lens ensures a reliable, self-sustaining water supply while simultaneously driving biodiversity conservation, soil preservation, and the mitigation of downstream pollution.

Technological innovations can further strengthen these approaches. Affordable drip irrigation systems improve water-use efficiency by delivering water directly to plant root zones and eliminating surface runoff and reducing evaporative losses (Rahman, 2025). Solar-powered pumps reduce energy costs and improve accessibility for remote farming communities (Sanogo et al., 2025). Mobile-phone-based irrigation advisory systems provide weather information and irrigation scheduling support that can improve decision-making and reduce water losses (WEF, 2025). Together, these innovations can contribute to the objective of producing more food with limited water resources and careful environmental protection against degradation.

POLICY IMPLICATIONS AND FUTURE OPPORTUNITIES

The integrated application of agroecology and irrigation in agricultural development programmes strongly aligns with the objectives of the Africa continental wide development frameworks – namely Malabo Declaration (African Union Commission, 2014) and Africa Agenda 2063 (African Union, 2015).

Both frameworks emphasise sustainable agricultural transformation, climate resilience, poverty reduction, and improved food security. The Malabo Declaration emphasizes accelerated agricultural growth, poverty reduction, and resilience building, while Agenda 2063 highlights sustainable agricultural transformations, together with climate adaptation, and improved water management as pillars of Africa's development vision for all. By linking ecological intensification with efficient water use, agroecology–irrigation synergies offer a scalable and context-appropriate strategy to increase productivity, enhance nutritional outcomes, and strengthen the long-term sustainability of African agri-food systems in the face of climate variability and socio-economic change. Future investments should prioritise community-based water harvesting systems, climate-smart irrigation technologies, farmer training programmes, and supportive policy environments that encourage integrated water and land management approaches (IFC, 2010). Attention should be given to strengthening extension services, NGO support and facilitating access to affordable irrigation technologies for smallholder farmers.

CONCLUSIONS

Agroecology and irrigation should not be viewed as competing approaches but rather as complementary components of sustainable agricultural development. Water availability remains a critical constraint to agroecological transitions across much of semi-arid sub-Saharan Africa. Appropriate irrigation interventions, particularly supplementary irrigation and rainwater harvesting, can substantially enhance the effectiveness and resilience of agroecological systems, thus complement the recycling and reduced synthetic inputs.

Evidence from South African case studies demonstrates that integrating water management innovations with agroecological practices can improve productivity, strengthen food and nutrition security, and increase resilience to climate variability. Such integration offers a practical pathway towards achieving sustainable and climate-resilient agricultural development across Africa.

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