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Review

Interlinkages between land use change, CSA, and food security under climate change in SSA: A scoping review synthesis

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Abstract: Sub-Saharan Africa (SSA) faces interconnected challenges of climate change, land-use transformation, and persistent food insecurity. In this scoping review, we synthesized evidence on the interlinkages among land-use change, climate-smart agriculture (CSA), and food security under climate change in SSA, with particular attention to synergies, trade-offs, and feedback mechanisms. Following the PRISMA-ScR framework, relevant literature published between 2000 and 2025 was systematically identified and screened, resulting in 17 studies that were included in the final synthesis. Extracted evidence was analyzed using descriptive and thematic approaches. Agricultural expansion, deforestation, land degradation, agricultural intensification, and landscape fragmentation emerged as the dominant land-use transformations. While agricultural expansion may increase production in the short term, associated ecosystem degradation can undermine long-term productivity and food security. CSA practices, particularly agroforestry, conservation agriculture, integrated soil fertility management, climate-resilient crop varieties, and sustainable land management were associated with improved productivity, climate resilience, ecosystem restoration, and food-security outcomes. However, their implementation involved trade-offs related to land allocation, labor, investment requirements, and environmental conservation. The findings highlighted positive feedbacks between CSA, land restoration, productivity, and resilience and support integrated, context-specific landscape approaches for achieving sustainable and climate-resilient agrifood systems in SSA.

Keywords: climate-smart agriculture; land use change; food security; climate change adaptation; Sub-Saharan Africa

1. Introduction

Sub-Saharan Africa (SSA) is confronted with the intertwined challenges of climate change, land use transformation, and persistent food insecurity, all of which threaten the sustainability of agricultural systems and rural livelihoods [1–3]. Agriculture remains the backbone of most economies in the region, contributing significantly to employment, income generation, and food provision for millions of households [4–6]. However, the sector is highly climate-sensitive [7–9] and vulnerable to increasing temperatures, erratic rainfall patterns, prolonged droughts, floods, and other extreme weather events associated with climate change [10–12]. These climatic stresses are expected to reduce agricultural productivity [13–15], undermine ecosystem services, and exacerbate food insecurity [16–18], particularly among smallholder farmers who depend heavily on rain-fed agriculture [19–21]. Food security in SSA remains a pressing development challenge despite decades of agricultural development interventions [22–24]. According to [25–27], the region continues to record the highest prevalence of undernourishment globally, with climate variability increasingly identified as a major driver of food system instability. The four dimensions of food security, availability, access, utilization, and stability, are directly influenced by environmental conditions and land-use decisions [28,29]. As climate change intensifies, achieving sustainable food security requires a comprehensive understanding of the interactions between agricultural production systems, land resources, and climate adaptation strategies.

Land use change has emerged as a critical factor shaping agricultural productivity and food security outcomes in SSA. Driven by population growth, urbanization, market expansion, and increasing demand for food, agricultural land has expanded considerably over recent decades, often at the expense of forests, wetlands, and other natural ecosystems [30–32]. While agricultural expansion can increase food production in the short term, it frequently contributes to deforestation, biodiversity loss, soil degradation, and greenhouse gas emissions, thereby undermining long-term ecosystem resilience and agricultural sustainability [33,34]. Lambin and Meyfroidt [35] argued that land use change represents a consequence and a driver of environmental change, creating complex feedback mechanisms that influence food production and climate adaptation capacity. In SSA, land degradation affects approximately 65% of productive land, reducing soil fertility, water retention capacity, and agricultural productivity [36–38]. The conversion of forests and rangelands into cropland often leads to declining ecosystem services that are essential for agricultural production, including nutrient cycling, pollination, and watershed protection [39,40]. Consequently, land use decisions have significant implications not only for food production but also for climate resilience and environmental sustainability. Understanding how land use dynamics interact with agricultural adaptation strategies is therefore crucial for promoting sustainable development pathways in the region.

In response to increasing climate risks and concerns about the sustainability of agricultural production, climate-smart agriculture (CSA) has emerged as an integrated framework for improving agricultural productivity and resource-use efficiency while strengthening resilience to climate change. CSA seeks to sustainably increase agricultural productivity and incomes, enhance adaptation and resilience, and reduce or remove greenhouse gas emissions where feasible [41]. These objectives can be pursued through technological and management innovations, including conservation agriculture, agroforestry, integrated soil fertility management, climate-resilient crop varieties, efficient water management, and climate-information technologies [42]. Beyond individual practices, technological

innovation is important because climate change and differences in production technologies can influence agricultural total factor productivity and production efficiency, while improvements in agricultural technology can enhance the efficiency with which critical resources such as water are utilized [43,44]. This efficiency perspective is particularly relevant under increasing land and water constraints, as productivity gains achieved through more efficient resource use may reduce incentives for extensive agricultural expansion. Agroforestry and conservation agriculture, for example, can improve soil quality, moisture retention, carbon storage, and ecosystem resilience, while climate-resilient varieties can reduce production losses under adverse climatic conditions [45,46]. CSA can therefore influence not only farm productivity and adaptation but also broader land-use decisions and food-security outcomes. However, the effectiveness of these technological and management interventions varies across agroecological, socioeconomic, and institutional contexts, necessitating an integrated synthesis of their relationships with land-use change and food security.

Despite a growing body of literature on land use change, CSA, and food security, these themes are often examined independently. Researchers tend to focus either on the effects of climate change on agricultural production, the adoption of CSA practices, or the consequences of land use change for environmental sustainability [45–47]. Relatively few researchers have adopted an integrated perspective that explicitly examines the interrelationships, synergies, trade-offs, and feedback loops among these three domains. Such fragmentation limits the ability of policymakers and development practitioners to design interventions that simultaneously address climate adaptation, sustainable land management, and food security objectives. Reviews have generated important but largely compartmentalized knowledge on the relationships among climate change, agricultural land use, CSA (CSA), and food security in SSA. Reviews of climate change and agriculture have predominantly examined climate impacts on crop productivity, vulnerability, and adaptation, while the CSA literature has largely synthesized the adoption, productivity, resilience, and mitigation benefits of individual climate-smart practices. Other evidence syntheses have concentrated on land-use change, deforestation, land degradation, sustainable intensification, or the implications of landscape transformation for ecosystem services and agricultural production. Although these bodies of evidence provide important insights, they generally address individual components or pairwise relationships within the broader land–climate–agriculture–food nexus. Consequently, there remains limited synthesis of how climate-driven land-use transformations interact with CSA interventions and subsequently influence food-security outcomes across agroecological contexts in SSA. In this scoping review, we address this gap by moving beyond the sectoral treatment of land-use change, CSA, and food security to examine them as components of an interconnected socio-ecological system under climate change. The novelty of the review lies in simultaneously mapping (i) dominant climate-related land-use transformations; (ii) CSA practices implemented across agroecological zones; (iii) the effects of land-use change on agricultural productivity and the four dimensions of food security; (iv) the pathways through which CSA interventions influence land-use decisions and food-security outcomes; and (v) the synergies, trade-offs, and positive and negative feedback mechanisms connecting these processes. By integrating these dimensions within a single evidence-synthesis framework, the review provides a nexus-based understanding that is not captured when land use, CSA, and food security are considered independently. This integrated perspective provides a basis for identifying research gaps and informing climate-smart landscape and food-system policies that simultaneously pursue agricultural productivity, ecosystem conservation, climate resilience, and food security in SSA. A scoping review is particularly appropriate because it enables the systematic identification, examination, and synthesis of diverse forms of evidence across disciplines and geographical contexts [48,49]. The study will assist policymakers in designing integrated land-use and agricultural policies that balance food production, environmental

conservation, and climate adaptation objectives. Identifying the synergies and trade-offs among land use practices, CSA interventions, and food security outcomes, the review will support evidence-based decision-making aimed at enhancing agricultural productivity while reducing environmental degradation. Furthermore, the findings will help governments prioritize investments in climate-smart technologies and sustainable land management strategies that improve the resilience of smallholder farmers, who constitute the majority of agricultural producers in the region.

2. Methodology

2.1. Research design

In this study, we adopted a scoping review research design to systematically map, synthesize, and analyze literature on the interlinkages between land use change, CSA (CSA), and food security under climate change in SSA (SSA). A scoping review was particularly appropriate for this study because the subject area was broad, multidisciplinary, and characterized by diverse forms of evidence. Unlike a traditional systematic review, which focuses on answering narrowly defined questions, a scoping review enables the identification of key concepts, evidence gaps, research trends, and emerging themes across a wide body of literature [48,49]. The review follows the methodological framework proposed by Arksey and O'Malley [48] and further refined by Levac et al. [49] and Levac et al. [50]. Relevant literature was sourced from major academic databases, including Scopus, Web of Science, ScienceDirect, Google Scholar, CAB Abstracts, and AGRICOLA, as well as grey literature from organizations such as the Food and Agriculture Organization (FAO), World Bank, International Food Policy Research Institute (IFPRI), and the Consultative Group on International Agricultural Research (CGIAR). We focused on studies conducted in SSA that addressed land use change, CSA, climate change adaptation, and food security. A systematic search strategy using predefined keywords and Boolean operators was employed to ensure comprehensive coverage of the literature. Selected studies underwnt a rigorous screening process involving title, abstract, and full-text reviews. Data extracted from eligible studies included publication details, study location, methodological approaches, land use change indicators, CSA interventions, food security outcomes, key findings, and policy implications. The synthesized evidence was analyzed using descriptive statistics and thematic content analysis to identify recurring patterns, research gaps, synergies, trade-offs, and knowledge priorities. The findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) (Figure 1) guidelines to ensure transparency, rigor, and reproducibility. Figure 1 summarizes the identification, screening, eligibility assessment, and inclusion stages of the review. A total of 1,320 records were identified from electronic databases and other sources, of which 320 duplicates were removed. Following title and abstract screening of 1,000 records, 900 studies were excluded. One hundred full-text articles were assessed for eligibility, with 83 studies excluded based on predefined criteria. Ultimately, 17 studies met the inclusion criteria and were included in the final qualitative synthesis. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines to ensure transparency, methodological rigor, and reproducibility.

Although 1,320 records were initially identified, only 17 studies met the eligibility criteria for the final synthesis. This relatively small number was not primarily a consequence of restrictive criteria regarding study design or publication type, as we considered qualitative, quantitative, and mixed-method studies as well as peer-reviewed and relevant grey literature. Rather, most retrieved studies examined climate change, land-use change, CSA, or food security independently or addressed only

selected relationships among these themes. The review required evidence relevant to their interconnected relationships within the SSA context. Consequently, the limited number of eligible studies highlights an important knowledge gap in integrated research examining the land use–CSA–food security nexus under climate change and underscores the need for further interdisciplinary and systems-oriented studies in the region.

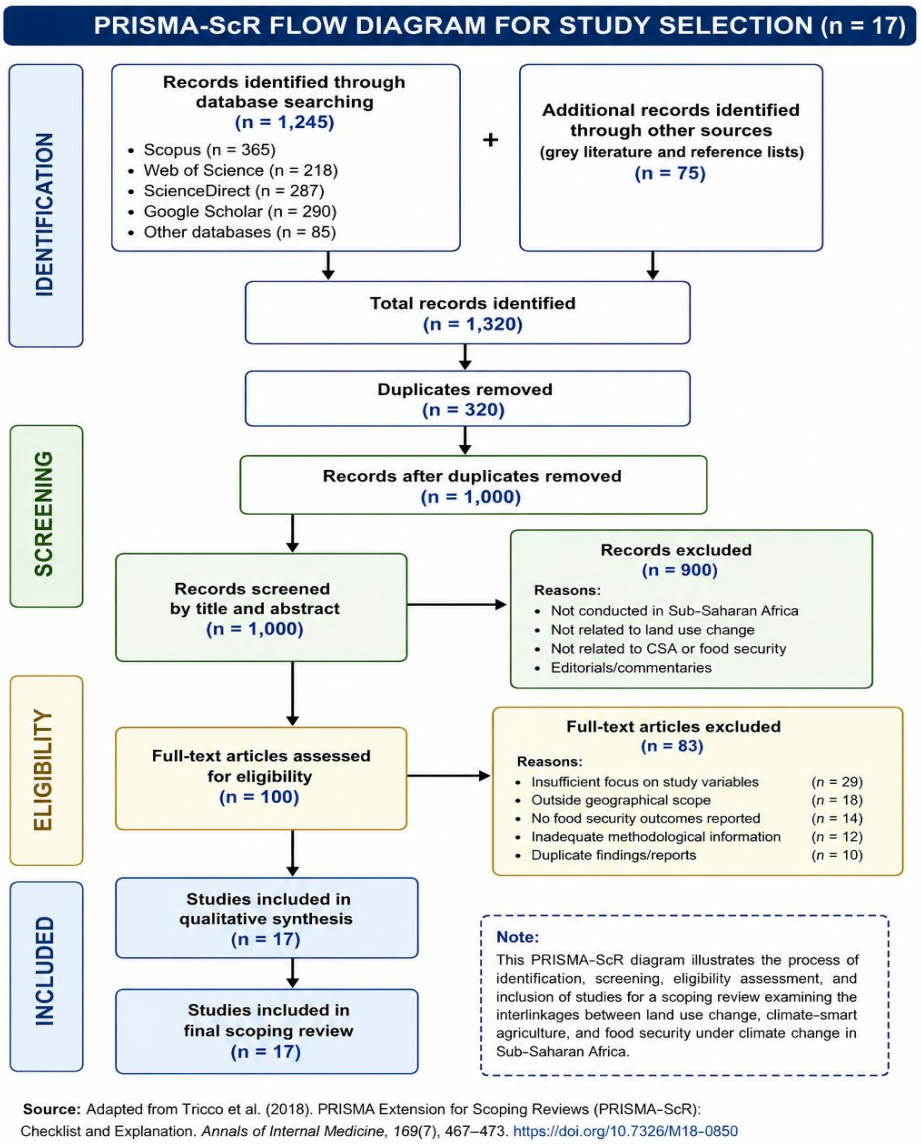


Figure 1. PRISMA-ScR flow diagram illustrating the study selection process for the scoping review on the interlinkages between land use change, CSA, and food security under climate change in SSA.

2.2. Inclusion and exclusion criteria

To ensure the relevance and quality of evidence synthesized in this scoping review, predefined inclusion and exclusion criteria were applied during the study selection process. We included peer-reviewed journal articles, conference papers, book chapters, and credible grey literature published by international organizations such as the FAO, World Bank, IFPRI, CGIAR, and UNEP. Eligible studies

must have entailed one or more of the key themes: land use change, CSA (CSA), climate change, and food security within the context of SSA. Qualitative, quantitative, and mixed-methods studies published in English between 2000 and 2025 were considered to capture contemporary developments and emerging trends in the field. Studies were excluded if they were conducted outside SSA or did not explicitly address the interrelationships among land use change, CSA, climate change, or food security. Editorials, commentaries, opinion papers, newspaper articles, unpublished theses, and studies lacking sufficient methodological detail were also excluded. Additionally, duplicate records identified across databases were removed during the screening process. Applying these criteria ensured that the review captured robust and relevant evidence necessary for understanding the complex interactions among land use change, CSA, and food security under climate change in SSA.

2.3. Source of data

We relied exclusively on secondary data obtained from published and unpublished literature relevant to land use change, CSA (CSA), food security, and climate change in SSA. Data were sourced from reputable academic databases, including Scopus, Web of Science, ScienceDirect, Google Scholar, CAB Abstracts, AGRICOLA, and SpringerLink. In addition, grey literature was obtained from international and regional organizations such as the Food and Agriculture Organization (FAO), World Bank, International Food Policy Research Institute (IFPRI), Consultative Group on International Agricultural Research (CGIAR), United Nations Environment Programme (UNEP), and the African Development Bank (AfDB). We included peer-reviewed journal articles, conference proceedings, policy reports, technical reports, working papers, and institutional publications that meet the predefined inclusion criteria. These sources provided comprehensive evidence on land-use dynamics, climate-smart agricultural interventions, climate change impacts, and food security outcomes across SSA, enabling a robust synthesis of existing knowledge and identification of research gaps.

2.4. Search strategy

A comprehensive and systematic search strategy was employed to identify relevant literature on the interlinkages between land use change, CSA (CSA), and food security under climate change in SSA. Electronic databases, including Scopus, Web of Science, ScienceDirect, Google Scholar, CAB Abstracts, and AGRICOLA, were searched using a combination of keywords and Boolean operators (AND, OR). Key search terms included: “land use change”, “land cover change”, “deforestation”, “CSA”, “sustainable agriculture”, “food security”, “food systems”, “climate change”, “climate resilience”, and “SSA”. The search strings were adapted to suit the indexing requirements of each database. Additional studies were identified through backward and forward citation tracking of selected articles. Grey literature from organizations such as FAO, IFPRI, CGIAR, World Bank, and UNEP was also searched to capture policy reports and technical documents. The search process was documented to ensure transparency, consistency, and reproducibility of the review. A comprehensive literature search was conducted to identify studies examining the interlinkages among land-use change, CSA (CSA), climate change, and food security in SSA. The searches covered studies published between January 2000 and December 2025. Search terms were organized around four major concepts: land-use change, CSA, food security, and climate change/SSA. Boolean operators (AND/OR), phrase searching, and database-specific search syntax were used to combine relevant terms. Backward and forward citation searching of eligible studies was also undertaken to identify additional relevant publications.

2.5. Study selection and screening procedure

All records retrieved from the databases were exported to Excel**,** where duplicate records were identified and removed. Following deduplication, two (2) reviewers independently screened the titles and abstracts of retrieved records against the predefined eligibility criteria. Studies considered potentially relevant proceeded to full-text assessment. Full-text articles were independently evaluated by two (2) reviewers using the same inclusion and exclusion criteria. Disagreements at either screening stage were resolved through discussion and consensus, and where consensus was not reached, a third-reviewer adjudication was sought. Reasons for exclusion at the full-text stage were documented. The study-selection process was summarized using the PRISMA-ScR flow diagram. Of the 1,320 records initially identified, 320 duplicates were removed, leaving 1,000 records for title and abstract screening. Following screening, 100 full-text articles were assessed for eligibility, of which 83 were excluded, resulting in 17 studies included in the final synthesis.

2.6. Data extraction and analysis

Data extraction was conducted using a standardized data-charting form developed specifically for this review. Information extracted from each eligible study included author(s), year of publication, country or study location, study objectives, research design, data sources, key land use change indicators, CSA (CSA) practices examined, food security dimensions assessed, climate change variables considered, major findings, and policy recommendations. Additional information on identified synergies, trade-offs, and interactions among land use change, CSA, and food security were also documented. The data extraction process was iterative, enabling refinement of categories as new themes emerged during the review. The extracted data were analyzed using descriptive and thematic approaches. Descriptive analysis summarized publication trends, geographical distribution of studies, methodological characteristics, and dominant research themes. Thematic content analysis was employed to identify recurring patterns, relationships, opportunities, challenges, and knowledge gaps relating to land use change, CSA, and food security under climate change. Findings were organized into thematic categories and presented using narrative synthesis, tables, charts, and evidence maps. This approach facilitated a comprehensive understanding of evidence, highlighted research priorities, and revealed critical areas requiring further investigation across SSA. The reporting of findings followed the PRISMA-ScR guidelines to ensure transparency and methodological rigor. Data from the 17 included studies were charted using a standardized extraction form developed in Excel. The form captured author(s), publication year, country, study objectives, research design, data sources, land-use change indicators, CSA practices, food-security dimensions, climate variables, major findings, policy implications, and reported synergies, trade-offs, and interactions. Data extraction was independently undertaken by the two authors using a standardized data-charting framework. The extracted information was subsequently compared and cross-checked for accuracy, completeness, and consistency. Any discrepancies between the reviewers were resolved through discussion and consensus, thereby minimizing extraction errors and enhancing the reliability of the review findings.

3. Results and discussion

3.1. Descriptive characteristics and synthesis of the included studies

The studies summarized in Table 1 demonstrate the multidimensional relationship among land-use change, CSA (CSA), and food security in SSA (SSA). A prominent theme is increasing pressure on agricultural land. The researchers in [35,51] associated population growth, land scarcity, and changing farming systems with agricultural expansion and ecosystem conversion. Searchinger et al. [52] further demonstrated that conversion of African wet savannahs to cropland may generate short-term production gains but entails substantial carbon and biodiversity costs. These findings illustrate an important trade-off between expanding food production and maintaining ecosystem services required for long-term agricultural sustainability. The manuscript similarly reveals agricultural expansion, deforestation, and degradation as dominant land-use transformations in SSA. The reviewed evidence nevertheless indicates that CSA provides pathways for reconciling agricultural production with environmental sustainability. The researchers in [45,53] found that conservation agriculture practices, including minimum tillage, permanent soil cover, and crop rotation, can improve soil moisture retention, reduce erosion, and enhance crop performance, particularly in semi-arid environments. Zougmoré [54] similarly emphasized integrated soil fertility management and water-harvesting approaches for addressing soil degradation and rainfall variability. Agroforestry represents another important pathway. The researchers in [40,55] associated tree integration with improved soil fertility, carbon sequestration, biodiversity conservation, ecosystem resilience, and livelihood diversification. Moreover, the researchers in [41,56] emphasized sustainable intensification and integrated production systems as mechanisms for increasing productivity while reducing environmental pressure. Climate-resilient varieties and related adaptation strategies also contribute to reducing production risks associated with drought, heat stress, and rainfall variability [22,46]. Collectively, the studies suggest that no single CSA practice is universally appropriate. Rather, effective interventions are context-specific and agroecologically differentiated, requiring integration of farm-level CSA with landscape-scale land management. This supports [40,57], who advocated landscape approaches that jointly address agricultural productivity, ecosystem conservation, climate resilience, and food security.

3.2. Thematic synthesis of the included studies

The thematic synthesis reveals strong interconnections among climate change, land-use transformation, CSA, and food security in SSA. Agricultural expansion and increasing land pressure constitute a dominant theme. Studies such as [35,51,52,58] indicated that population growth, increasing food demand, climate stress, and declining land productivity encourage cropland expansion into natural ecosystems. Although such expansion may increase food production in the short term, associated deforestation, biodiversity loss, and degradation of ecosystem services can undermine long-term productivity and food-security stability. The manuscript similarly reveals agricultural expansion, deforestation, land degradation, and landscape fragmentation as interconnected land-use challenges.

A second major theme concerns CSA as a pathway for reversing land degradation while strengthening agricultural resilience. Conservation agriculture, particularly minimum tillage, permanent soil cover, and crop rotation, is associated with improved soil-moisture retention, reduced erosion, and enhanced crop performance under drought conditions [45,53]. Integrated soil fertility management and water harvesting are particularly relevant to degraded and water-constrained farming systems [54]. Agroforestry provides complementary benefits through soil-fertility improvement,

carbon sequestration, biodiversity conservation, microclimate regulation, and livelihood diversification [40,55].

Importantly, the synthesis identifies synergies and trade-offs. Sustainable intensification can improve productivity while reducing pressure for further agricultural expansion [56], whereas agroforestry and conservation agriculture can simultaneously enhance ecosystem services and agricultural resilience. However, CSA adoption may involve land, labor, knowledge, investment, and delayed-return constraints, while agricultural expansion creates a fundamental trade-off between immediate production and long-term environmental sustainability. Collectively, the evidence supports integrated, context-specific landscape approaches rather than isolated interventions. Nevertheless, the limited number of studies simultaneously examining land use, CSA, and food security highlights an important knowledge gap and the need for longitudinal, spatially explicit, and systems-based research.

Table 1. Descriptive characteristics and key findings of the 17 studies included in this scoping review.

No.	Study	Geographical focus/context	Major land-use/land-management issue	CSA/adaptation practice or pathway	Food-security/productivity outcome	Main finding/contribution
1	[35]	Global, with relevance to SSA	Agricultural expansion, land scarcity and ecosystem conversion	Sustainable/intensified land management	Food production and long-term land availability	Agricultural expansion can increase production but creates competition for land and environmental pressures; sustainable intensification is required to reduce further ecosystem conversion.
2	[57]	Developing-country agricultural landscapes, including SSA	Competing agricultural and conservation land uses	Climate-smart landscape approaches	Productivity, livelihood resilience and food security	Landscape-level management can integrate agricultural production, ecosystem conservation and climate resilience more effectively than isolated farm-level interventions.
3	[59]	Global food systems, including developing regions	Climate-induced pressures on agricultural land and food systems	Climate adaptation and mitigation within food systems	Food availability, access and stability	Climate change affects food security through agricultural production, livelihoods and food-system processes, demonstrating the need for integrated adaptation strategies.
4	[56]	Developing regions/SSA	Pressure for agricultural intensification	Sustainable intensification; integrated crop–livestock management	Increased productivity and resilience	Sustainable intensification can increase output from existing agricultural land and potentially reduce pressure for further conversion of natural ecosystems.
5	[53]	Multiple African farming systems	Soil degradation, erosion and declining soil productivity	Conservation agriculture: minimum tillage, soil cover and crop rotation	Improved soil moisture and potentially more stable crop production	Conservation agriculture can improve soil and water management, although outcomes and adoption depend strongly on local conditions and resource constraints.
6	[51]	Africa	Increasing land pressure, declining farm size, agricultural expansion and changing farming systems	Agricultural intensification and improved land management	Agricultural productivity and livelihood sustainability	Population pressure and declining farm sizes are transforming African farming systems and creating greater need for productivity-enhancing intensification rather than continued land expansion.

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No.	Study	Geographical focus/context	Major land-use/land-management issue	CSA/adaptation practice or pathway	Food-security/productivity outcome	Main finding/contribution
7	[41]	Developing countries, including SSA	Unsustainable agricultural land management under climate change	CSA, including improved varieties, soil and water management and sustainable intensification	Productivity, adaptation/resilience and food security	CSA can simultaneously support agricultural productivity, climate adaptation and mitigation, although implementation needs to reflect local conditions.
8	[55]	Africa	Deforestation, declining tree cover and degraded agricultural landscapes	Agroforestry/tree integration	Improved productivity, diversified livelihoods and resilience	Agroforestry enhances soil fertility, carbon storage, biodiversity and livelihood diversification while contributing simultaneously to climate adaptation and mitigation.
9	[52]	African wet savannahs	Conversion of savannah ecosystems to cropland	Avoided conversion/sustainable intensification	Short-term production gains versus long-term sustainability	Expansion of cropland into wet savannahs carries substantial carbon and biodiversity costs, highlighting major trade-offs between agricultural expansion and environmental conservation.
10	[45]	Southern Africa, particularly rain-fed/semi-arid farming systems	Soil degradation, erosion and moisture stress	Conservation agriculture, crop rotation, minimum tillage and permanent soil cover	Improved soil moisture, drought resilience and crop yields	Conservation agriculture can strengthen productivity and resilience under variable rainfall by improving soil structure and moisture retention.
11	[22]	SSA/West Africa	Climate-induced land degradation and productivity decline	Climate adaptation and climate-resilient production	Crop productivity and food security	Increasing temperatures, drought and rainfall variability threaten agricultural productivity and food security, particularly in rain-fed smallholder systems.
12	[40]	Tropical landscapes, including SSA	Deforestation, tree-cover loss and declining ecosystem services	Agroforestry and landscape restoration	Food production, income diversification and livelihood resilience	Trees provide important ecosystem services, including soil fertility, water regulation and biodiversity, that support food production and rural livelihoods.

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No.	Study	Geographical focus/context	Major land-use/land-management issue	CSA/adaptation practice or pathway	Food-security/productivity outcome	Main finding/contribution
13	[54]	West African/Sahelian farming systems	Land degradation, declining soil fertility and water stress	Integrated soil fertility management, water harvesting and sustainable land management	Increased productivity and climate resilience	Combining soil-fertility and water-management practices can restore degraded land and improve productivity and resilience under erratic rainfall.
14	[46]	SSA smallholder farming systems	Climate vulnerability and declining agricultural productivity	CSA and climate-resilient crop varieties	Yield stability, adaptation and food security	CSA practices improve smallholder adaptive capacity and can reduce production losses associated with drought, heat and rainfall variability.
15	[58]	Africa	Land pressure, continuous cultivation, soil fertility decline and rural transformation	Sustainable agricultural intensification	Productivity and long-term food production	Growing land scarcity makes sustainable intensification increasingly important; continuous cultivation without soil restoration contributes to declining productivity and pressures for further land expansion.
16	[42]	SSA/developing-country CSA context	Resource degradation and climate-related production risks	Multiple CSA technologies and management practices	Productivity, resilience and food security	CSA comprises context-specific technological and management options whose effectiveness depends on farming systems, environmental conditions and implementation context.
17	[47]	Tropical/SSA land-use context	Agricultural expansion, land-use transitions and environmental change	Sustainable land-use/intensification pathways	Food production and environmental sustainability	Land-use and agricultural transitions create both production opportunities and environmental costs, emphasizing the need to integrate land-use planning with sustainable agricultural development.

*Note: Source: Authors' compilation from 17 studies.

Table 2. Thematic synthesis of land-use change, climate-smart agriculture, and food-security interlinkages across the included studies.

Major theme	Sub-theme / evidence pattern	Studies contributing to the theme	Synthesized findings	Implications for food security
1. Agricultural expansion and land pressure	Cropland expansion; declining farm sizes; conversion of forests and savannahs; increasing competition for land	[35,51,52,58]	Population growth, food demand, climate stress and declining land productivity encourage agricultural expansion. Increasing land pressure is also transforming traditional farming systems and encouraging intensification.	Expansion may increase food production in the short term but threatens long-term food availability and stability through degradation of natural resources.
2. Deforestation and ecosystem-service loss	Forest conversion; tree-cover loss; biodiversity decline; weakening of ecosystem services	[40,52,55]	Agricultural expansion and unsustainable land management contribute to forest and tree-cover loss, reducing carbon sequestration, biodiversity, water regulation and soil-supporting ecosystem services.	Loss of ecosystem services can reduce agricultural productivity and increase vulnerability to droughts and other climatic shocks.
3. Land degradation and declining soil fertility	Soil erosion; nutrient depletion; declining organic matter; continuous cultivation; water stress	[22,54,55,58]	Unsustainable cultivation and climatic stresses contribute to deteriorating soil quality and declining productivity, which may encourage further agricultural expansion.	Lower productivity reduces food availability and farm income and increases household vulnerability to food insecurity.
4. Conservation agriculture and sustainable land management	Minimum tillage; permanent soil cover; crop rotation; soil and water conservation	[45,53,54]	Conservation agriculture improves soil moisture retention, reduces erosion and supports crop production under drought and variable rainfall conditions.	Greater yield stability and resilience strengthen food availability and stability, particularly in semi-arid farming systems.
5. Agroforestry and ecosystem restoration	Tree–crop integration; alley cropping; parkland systems; landscape restoration	[40,55,57]	Agroforestry enhances soil fertility, biodiversity, carbon storage, microclimate regulation and ecosystem resilience while contributing to landscape restoration.	Supports food availability through productivity improvements and food access through diversification of farm products and household income.
6. Sustainable agricultural intensification	Increasing productivity on existing farmland; integrated crop–livestock systems; improved pasture and resource management	[41,56,58]	Sustainable intensification offers an alternative to extensive agricultural expansion by increasing productivity and resource-use efficiency on existing agricultural land.	Higher productivity can improve food availability and income while reducing pressure to convert additional natural ecosystems.

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Major theme	Sub-theme / evidence pattern	Studies contributing to the theme	Synthesized findings	Implications for food security
7. Climate-resilient technologies and adaptation	Drought-tolerant varieties; improved cereals; water management; adaptation to rainfall and temperature variability	[22,41,46,54]	CSA technologies reduce vulnerability to drought, heat stress and irregular rainfall and strengthen smallholder adaptive capacity.	Reduced production variability contributes particularly to food availability and stability under climate change.
8. Synergies between CSA, land management and food security	Soil restoration–productivity synergy; sustainable intensification–land conservation synergy; agroforestry–ecosystem service synergy	[40,54–59,]	CSA can simultaneously restore degraded resources, increase productivity, improve ecosystem services and reduce pressure for further agricultural expansion.	Synergies potentially improve several dimensions of food security while strengthening long-term agricultural resilience.
9. Trade-offs in land use and CSA adoption	Production versus conservation; trees versus annual crops; adoption costs; labor and knowledge requirements	[35,52,53,55]	Short-term agricultural expansion may conflict with long-term ecosystem conservation. Some CSA practices require land, labor, knowledge, investment or delayed returns.	Resource-constrained farmers may face barriers to realizing the food-security benefits of CSA despite its long-term advantages.
10. Feedback mechanisms	Degradation–expansion negative feedback; CSA–productivity–investment positive feedback; restoration–resilience feedback	[40,51,54]	Declining productivity can stimulate further land clearing and degradation. Conversely, improved soil fertility and productivity from CSA can increase income and encourage further investment in sustainable land management.	Negative feedbacks exacerbate food insecurity, whereas positive CSA feedbacks strengthen productivity, income, resilience and food-security stability.
11. Integrated landscape approaches	Linking agriculture, forestry, biodiversity, ecosystem management and livelihoods	[40,41,57]	Farm-level interventions alone may be insufficient to address interconnected climate, land-use and food-security challenges; coordinated landscape management is needed.	Integrated approaches can simultaneously support production, livelihood resilience, ecosystem conservation and sustainable food security.
12. Evidence and research gaps	Limited integrated nexus studies; lack of longitudinal and spatial evidence; context-specific outcomes	Evidence synthesized across the included studies	Existing evidence often examines land-use change, CSA and food security independently or through pairwise relationships rather than simultaneously. Longitudinal and spatially explicit evidence remains limited.	Limits understanding of long-term effects of CSA and land-use transformation on all four dimensions of food security.

*Note: Source: Authors' compilation from 17 studies.

3.3. Major land use change patterns associated with climate change in SSA: Evidence from the selected studies

The studies included in this scoping review revealed that climate change is a driver and consequence of significant land use changes across SSA (SSA). These changes are reshaping agricultural landscapes, influencing ecosystem services, and affecting food security outcomes. Five major land use change patterns emerged consistently across the reviewed literature.

Agricultural Expansion into Forests and Savannah Ecosystems

The most prominent land use change pattern identified is the expansion of cropland into forests, woodlands, and savannah ecosystems. Growing food demand driven by rapid population growth and declining agricultural productivity under climate stress has encouraged the conversion of natural vegetation into agricultural land [35,51]. Searchinger et al. [52] found that Africa's wet savannahs are increasingly targeted for agricultural expansion, despite the substantial carbon emissions and biodiversity losses associated with land conversion. This trend is particularly evident in West and Central Africa, where forest frontiers continue to shrink as cultivation expands.

Deforestation and loss of tree cover

Several studies identified deforestation as a major consequence of agricultural expansion and unsustainable land management practices. The removal of forests for crop cultivation, fuelwood extraction, and settlement development reduces carbon sequestration capacity and increases vulnerability to climate shocks [40,55]. Forest degradation further weakens ecosystem services such as soil fertility enhancement, watershed protection, and microclimate regulation, all of which are critical for sustainable agricultural production and food security.

Land degradation and declining soil fertility

Land degradation emerged as one of the most widespread land use changes associated with climate change in SSA. Climate-induced droughts, erratic rainfall, soil erosion, nutrient depletion, and unsustainable farming practices have accelerated the deterioration of productive agricultural lands [22,53]. Jayne et al. [58] argued that increasing land pressure and continuous cultivation without adequate soil restoration have resulted in declining farm productivity across many parts of SSA. Degraded lands often force farmers to clear new areas, thereby perpetuating a cycle of environmental degradation.

Agricultural intensification and adoption of climate-smart land management

A contrasting land use pattern observed in the literature is the gradual shift toward sustainable intensification and CSA (CSA). Several studies reported increasing adoption of conservation agriculture, agroforestry, integrated soil fertility management, and sustainable land management practices as adaptation strategies to climate change [41,45,54]. Agroforestry systems, in particular, promote the integration of trees into farming landscapes, enhancing carbon storage, improving soil quality, and reducing pressure on natural forests [55]. These practices represent a transition from extensive land expansion toward more efficient and sustainable land use systems.

Landscape fragmentation and transformation of traditional farming systems

Climate change, population growth, and market integration have contributed to increasing fragmentation of agricultural landscapes and transformation of traditional farming systems. Jayne et al. [51] found that declining farm sizes and increasing competition for land have altered land tenure arrangements and land use patterns across many African countries. Fragmented landscapes often reduce ecological connectivity, limit biodiversity conservation, and constrain the effectiveness of ecosystem-based adaptation strategies. Scherr et al. [57] emphasized the need for climate-smart landscape approaches that integrate agricultural production, ecosystem conservation, and climate

resilience across landscapes rather than individual farms.

Ultimately, the reviewed studies demosntrated that land use change in SSA is characterized by a complex interaction between climate change, population pressures, agricultural development, and food security needs. Agricultural expansion, deforestation, and land degradation remain dominant patterns, while CSA and sustainable intensification are emerging as promising pathways for reducing environmental pressures and enhancing resilience. The evidence suggests that future land use policies should prioritize integrated landscape management approaches that simultaneously support food production, ecosystem conservation, and climate adaptation to achieve sustainable food security in the region.

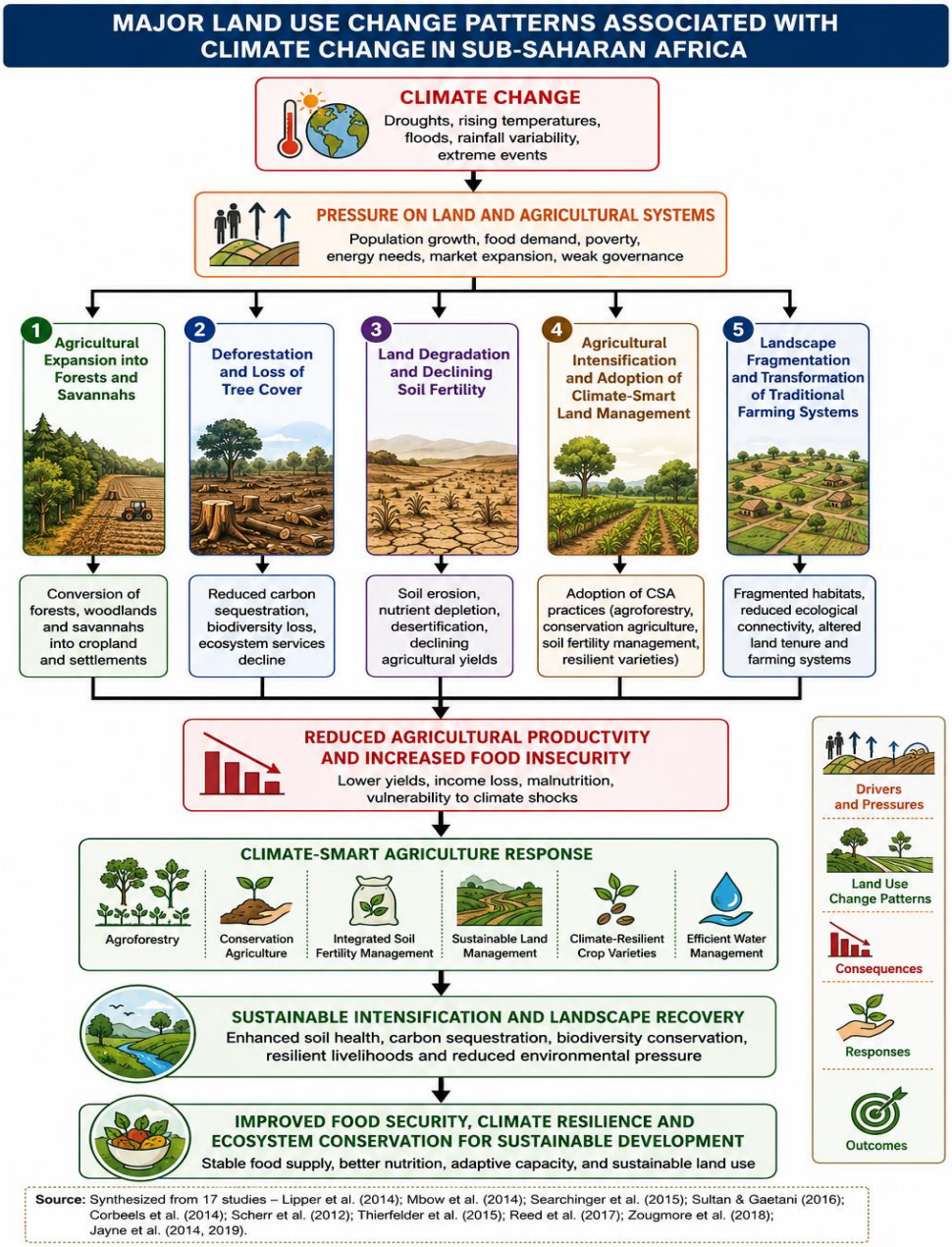


Figure 2. Major land use change patterns associated with climate change in SSA and the role of CSA in enhancing food security. Source: Author's visualization of 17 studies.

Figure 2 illustrates the major pathways through which climate change drives land use transformations in SSA. Climate-related stressors, including rising temperatures, droughts, floods, and rainfall variability, exert pressure on agricultural systems, resulting in agricultural expansion into forests and savannahs, deforestation and loss of tree cover, land degradation and declining soil fertility, landscape fragmentation, and changes in traditional farming systems. These land use changes contribute to declining agricultural productivity, biodiversity loss, reduced ecosystem services, and increased food insecurity. The figure further highlights the role of CSA (CSA) interventions, including agroforestry, conservation agriculture, integrated soil fertility management, sustainable land management, climate-resilient crop varieties, and efficient water management, in promoting sustainable intensification, ecosystem restoration, climate resilience, and improved food security. Collectively, these interventions provide pathways toward sustainable land use, resilient livelihoods, and environmentally sustainable agricultural development in SSA [51–53].

3.4. Climate-smart agricultural practices implemented across agroecological zones in SSA

The studies included in this scoping review revealed that CSA (CSA) has emerged as a critical strategy for enhancing agricultural productivity, climate resilience, and food security across diverse agroecological zones in SSA (SSA). The reviewed literature demonstrated that CSA practices vary according to climatic conditions, farming systems, land-use pressures, and ecological characteristics, but all aim to address the dual challenges of climate change adaptation and sustainable food production.

Semi-arid and dryland agroecological zones

In the semi-arid regions of Southern and West Africa, characterized by low and highly variable rainfall, recurrent droughts, and declining soil fertility, conservation agriculture (CA) is one of the most widely promoted CSA practices. The researchers in [45,53] found that minimum tillage, permanent soil cover, and crop rotation improve soil moisture retention, reduce erosion, and enhance crop yields under drought conditions. These practices are particularly important in countries such as Zimbabwe, Zambia, Malawi, and Mozambique, where climate variability increasingly threatens rain-fed agriculture. In the Sahel and Sudan Savannah zones of West Africa, integrated soil fertility management (ISFM) and water-harvesting technologies have been extensively adopted to restore degraded soils and improve water-use efficiency. The researchers in [54] reported that combining organic amendments with inorganic fertilizers significantly improves productivity and resilience among smallholder farmers facing erratic rainfall patterns.

Humid and sub-humid tropical zones

In the humid forest and sub-humid regions of Central and West Africa, agroforestry systems emerged as one of the most prominent CSA practices. The researchers in [40,55] found that the integration of trees into agricultural landscapes as a strategy for enhancing soil fertility, increasing carbon sequestration, improving biodiversity conservation, and diversifying household income. Agroforestry practices such as alley cropping, parkland systems, and tree-crop integration have been widely implemented in countries including Nigeria, Ghana, Cameroon, and Côte d'Ivoire. The studies further indicate that agroforestry contributes to climate adaptation by improving microclimatic conditions, reducing soil erosion, and increasing ecosystem resilience. Scherr et al. [57] described these systems as essential components of climate-smart landscapes that simultaneously support agricultural production and environmental conservation.

Mixed crop-livestock systems

Across Eastern and Southern Africa, where mixed crop-livestock systems dominate, CSA interventions emphasize sustainable intensification**,** improved livestock management**,** and climate-

resilient crop varieties. The researchers in [41,56] found that improved pasture management, rotational grazing, drought-tolerant crops, and integrated crop-livestock systems enhance productivity while reducing environmental pressures on land resources. Climate-resilient crop varieties, including drought-tolerant maize and improved cereal cultivars, have been increasingly promoted to help farmers cope with changing climatic conditions. These technologies reduce yield losses associated with heat stress, drought, and irregular rainfall [22,46].

Landscape-level approaches

Several studies advocate a transition from farm-level interventions to climate-smart landscape approaches that integrate agriculture, forestry, biodiversity conservation, and ecosystem management. The researchers in [40,57] argued that landscape-scale planning is necessary to address the interconnected challenges of land degradation, deforestation, and food insecurity. Such approaches promote coordinated land-use management across ecosystems and agroecological zones. Conclusively, the reviewed studies indicate that conservation agriculture dominates in semi-arid regions, agroforestry is most prevalent in humid and sub-humid zones, while integrated soil fertility management, climate-resilient crop varieties, sustainable livestock management, and climate-smart landscape approaches are increasingly implemented across agroecological zones. Collectively, these CSA practices enhance productivity, strengthen climate resilience, improve natural resource management, and contribute to food security throughout SSA [41,57].

3.5. Impacts of land use change on agricultural productivity and food security in SSA

Evidence synthesized from the studies included in this scoping review demonstrates that land use change has profound implications for agricultural productivity and food security across SSA (SSA). The reviewed literature showed that climate change, population growth, market expansion, and increasing pressure on natural resources have accelerated land-use transformations, creating opportunities and challenges for agricultural development. While some land-use changes have increased agricultural production in the short term, many have generated long-term environmental and socio-economic consequences that undermine food security and climate resilience. One of the most significant impacts of land use change is the expansion of agricultural land into forests, woodlands, and savannah ecosystems. The researchers in [35,51,52] found that growing food demand and rising population pressures have encouraged the conversion of natural ecosystems into cropland. Although agricultural expansion initially increases cultivated area and food production, it often results in deforestation, biodiversity loss, and the degradation of ecosystem services that support long-term agricultural productivity. Searchinger et al. [52] particularly emphasized that the conversion of African wet savannahs to cropland entails substantial carbon and biodiversity costs, reducing the sustainability of agricultural systems. The reviewed studies consistently revealed land degradation as one of the most serious consequences of unsustainable land use change. Soil erosion, nutrient depletion, declining soil organic matter, and desertification have become widespread across many farming systems in SSA [22,52]. Continuous cultivation without adequate soil restoration practices has reduced soil fertility and limited crop yields, particularly among smallholder farmers. As productive land becomes degraded, farmers often respond by clearing additional land, creating a cycle of agricultural expansion and environmental degradation. This pattern contributes to declining agricultural productivity and increasing vulnerability to climate shocks.

The loss of forests and tree cover further affects agricultural productivity by reducing ecosystem services that are critical for farming systems. The researchers in [40,55] highlighted the role of trees in enhancing soil fertility, regulating water cycles, reducing erosion, and supporting pollination

services. Deforestation weakens these ecological functions, leading to reduced crop performance and greater susceptibility to droughts and floods. In many regions, the removal of natural vegetation has also contributed to local climatic changes, including increased temperatures and reduced rainfall infiltration, further constraining agricultural productivity. Land use change also influences food security through its effects on agricultural output, income generation, and livelihood resilience. The reviewed studies indicated that declining land productivity directly reduces food availability and household income, thereby limiting access to food. The researchers in [22,59] noted that climate-induced land degradation and changing land-use patterns are increasingly linked to food insecurity, malnutrition, and livelihood vulnerability across SSA. Smallholder farmers, who depend heavily on rain-fed agriculture, are particularly affected because they often lack the resources needed to adapt to declining land quality.

Despite these challenges, several studies revealed positive pathways through which land use change can enhance agricultural productivity and food security when guided by sustainable land management principles. CSA (CSA) interventions such as conservation agriculture, agroforestry, integrated soil fertility management, and sustainable intensification have been shown to improve land productivity while reducing environmental degradation [41,45,54]. Agroforestry systems, for example, increase soil fertility, improve water retention, diversify farm income, and enhance resilience to climate variability [55]. Similarly, conservation agriculture improves soil structure and moisture retention, resulting in more stable crop yields under drought conditions [45,55]. The literature also highlights the importance of climate-smart landscape approaches, which integrate agricultural production, ecosystem conservation, and sustainable land management. Scherr et al. [57] argued that landscape-level interventions can simultaneously improve food production, protect natural resources, and strengthen climate resilience. Such approaches reduce the need for further agricultural expansion while enhancing the productivity of existing agricultural lands. Moreover, the reviewed studies demonstrate that land use change exerts direct and indirect effects on agricultural productivity and food security in SSA. While agricultural expansion may provide short-term gains in food production, unsustainable land-use practices often lead to land degradation, ecosystem decline, and reduced resilience. Conversely, sustainable land management and climate-smart agricultural practices offer pathways for restoring degraded landscapes, improving productivity, and strengthening food security under changing climatic conditions. The evidence underscores the need for integrated land-use policies that balance agricultural growth with environmental sustainability and long-term food system resilience.

3.6. How CSA (CSA) interventions influence land use decisions and food security outcomes in SSA

Evidence synthesized from the selected studies indicates that CSA (CSA) interventions significantly influence land use decisions and food security outcomes across SSA (SSA). By promoting sustainable intensification, resource-use efficiency, ecosystem restoration, and climate resilience, CSA practices alter how farmers manage land resources and respond to climate-related risks. The reviewed literature demonstrates that CSA not only affects agricultural productivity but also shapes broader land-use trajectories and household food security. One of the most important ways CSA influences land use decisions is by reducing the need for agricultural expansion into natural ecosystems. Conventional responses to declining yields often involve clearing forests, woodlands, and savannahs to create additional farmland. However, CSA practices such as conservation agriculture, integrated soil fertility management, and improved crop varieties increase productivity on existing agricultural land, thereby reducing pressure to convert natural ecosystems [41,56]. Moreover, by improving yields per

unit area, farmers can meet production needs without continuously expanding cultivated land, contributing to more sustainable land-use patterns. The reviewed studies also showed that agroforestry systems strongly influence land-use decisions by integrating trees into agricultural landscapes. The researchers in [40,55] found that agroforestry encourages farmers to adopt multifunctional land-use systems that simultaneously support crop production, soil conservation, biodiversity enhancement, and carbon sequestration. Furthermore, rather than viewing trees as obstacles to cultivation, farmers increasingly recognize them as productive assets that improve soil fertility, regulate microclimates, and diversify household income. Consequently, agroforestry contributes to a shift from extractive land-use practices toward more sustainable and ecologically integrated farming systems.

Similarly, conservation agriculture (CA) influences land management decisions by promoting minimum tillage, permanent soil cover, and crop diversification. The researchers in [45,53] reported that these practices improve soil structure, reduce erosion, enhance water infiltration, and maintain soil moisture. As farmers observe improvements in soil quality and crop performance, they become more likely to invest in long-term land stewardship rather than engaging in short-term land exploitation. This contributes to the restoration of degraded lands and supports sustainable intensification strategies. The studies further indicate that CSA interventions promote land restoration and rehabilitation in areas affected by degradation. Integrated soil fertility management, water-harvesting technologies, and sustainable land management practices improve soil health and productivity on previously degraded lands [54]. These interventions reduce the need to abandon degraded farms and clear new land elsewhere, thereby limiting further environmental degradation. In this way, CSA facilitates more efficient and sustainable use of existing land resources. At the landscape level, CSA encourages integrated land-use planning and climate-smart landscape approaches. Scherr et al. [57] emphasized that climate-smart landscapes seek to balance agricultural production, ecosystem conservation, and livelihood improvement across landscapes. Such approaches encourage coordinated decision-making among farmers, communities, and policymakers, helping to reduce conflicts among competing land uses while enhancing ecosystem resilience.

Regarding food security outcomes, the reviewed studies consistently demonstrate that CSA contributes positively to all four dimensions of food security: availability, access, utilization, and stability. First, CSA improves food availability through increased agricultural productivity. Practices such as improved crop varieties, conservation agriculture, and integrated nutrient management enhance crop yields and reduce production losses associated with climate variability [22,41]. Increased production directly strengthens local food supplies and reduces vulnerability to food shortages. Second, CSA enhances food access by increasing farm income and livelihood diversification. Agroforestry systems provide additional sources of income from fruits, timber, fuelwood, and non-timber forest products, while improved productivity increases marketable surpluses [40]. Higher incomes improve households' ability to purchase food and invest in productive assets. Third, CSA contributes to improved food utilization through enhanced dietary diversity and nutritional outcomes. Diversified farming systems, particularly agroforestry and integrated crop-livestock systems, provide access to a broader range of food products, including fruits, vegetables, livestock products, and legumes. These diversified diets contribute to improved nutrition and household well-being. Finally, CSA strengthens food stability by enhancing resilience to climate shocks. Climate-resilient crop varieties, water management technologies, and sustainable land management practices reduce vulnerability to droughts, floods, and rainfall variability [46,54]. As a result, households are better able to maintain food production and consumption during periods of environmental stress. Conclusively, the reviewed literature demonstrates that CSA interventions influence land use decisions by promoting sustainable intensification, reducing pressure on natural ecosystems, encouraging land restoration, and supporting

integrated landscape management. Furthermore, these interventions improve food availability, access, utilization, and stability, making CSA a critical pathway for achieving sustainable food security and climate resilience in SSA.

3.7. Synergies, trade-offs, and feedback mechanisms among land use change, CSA, and food security in SSA

The reviewed studies revealed that the relationships among land use change, CSA (CSA), and food security in SSA (SSA) are characterized by complex synergies, trade-offs, and feedback mechanisms. These interactions shape the sustainability of agricultural systems and influence the capacity of households and communities to adapt to climate change while maintaining food security. Understanding these interconnections is essential for designing policies and interventions that simultaneously address agricultural productivity, environmental conservation, and climate resilience.

Synergies among land use change, CSA, and food security

A major synergy identified in the literature is the ability of CSA practices to simultaneously enhance agricultural productivity, improve ecosystem services, and strengthen food security. Practices such as agroforestry, conservation agriculture, integrated soil fertility management, and sustainable land management increase crop yields while improving soil health, water retention, and carbon sequestration [41,55]. These improvements reduce pressure on natural ecosystems by increasing productivity on agricultural land, thereby limiting the need for agricultural expansion into forests and savannahs. Agroforestry represents one of the strongest examples of synergy. By integrating trees into farming systems, agroforestry improves soil fertility, reduces erosion, enhances biodiversity, and diversifies household income through the production of fruits, timber, fodder, and non-timber forest products [40]. These benefits contribute simultaneously to climate adaptation, mitigation, and food security. Similarly, conservation agriculture enhances soil moisture retention and nutrient availability, resulting in more stable crop yields under variable climatic conditions [45]. Another important synergy emerges through sustainable intensification. Increased productivity from CSA interventions reduces the need to convert additional land for agriculture, thereby preserving ecosystem services that support long-term food production [56]. Improved ecosystem health subsequently enhances agricultural resilience, creating mutually reinforcing benefits for land sustainability and food security.

Trade-offs among land use change, CSA, and food security

Despite these synergies, the reviewed studies highlighted several trade-offs associated with land-use decisions and CSA implementation. One common trade-off involves balancing short-term food production objectives with long-term environmental sustainability. Agricultural expansion into forests and natural ecosystems may increase food production in the short term but often leads to deforestation, biodiversity loss, soil degradation, and greenhouse gas emissions that undermine future agricultural productivity and resilience [35,52]. Certain CSA practices also involve trade-offs at the farm level. Agroforestry systems, for example, may require allocating land to trees that could otherwise be used for annual crop production. Although trees provide long-term ecological and economic benefits, farmers may experience temporary reductions in cultivated area or delayed returns on investment [55]. Similarly, conservation agriculture often requires substantial labor, technical knowledge, and initial investments, which can limit adoption among resource-constrained smallholders [53]. Trade-offs may also arise between adaptation and mitigation objectives. Some interventions designed to maximize agricultural productivity may increase input use, water extraction, or energy consumption, potentially generating environmental costs. Consequently, achieving optimal outcomes requires careful consideration of local ecological, economic, and social contexts.

Feedback mechanisms

The reviewed literature identified several feedback mechanisms linking land use change, CSA, and food security. One important feedback loop involves land degradation and agricultural expansion. Climate change and unsustainable land use practices reduce soil fertility and crop productivity, leading farmers to clear additional land to maintain production levels [51]. This expansion contributes to further deforestation and ecosystem degradation, which in turn exacerbates climate change and reduces agricultural resilience. The result is a reinforcing negative feedback cycle of declining productivity and increasing environmental degradation. Conversely, CSA interventions can generate positive feedback mechanisms. Improved soil fertility, water management, and productivity increase household food security and farm income, enabling farmers to invest further in sustainable land management practices [54]. Enhanced ecosystem services, such as improved water regulation and carbon sequestration, further strengthen agricultural resilience to climate variability. This creates a virtuous cycle in which sustainable land management improves productivity, food security, and environmental sustainability simultaneously. Another positive feedback mechanism occurs through agroforestry and landscape restoration. Increased tree cover improves soil quality and biodiversity while enhancing carbon storage and climate resilience. Improved environmental conditions subsequently support higher agricultural productivity and more stable food supplies, reinforcing incentives for continued adoption of sustainable practices [40]. Furthermore, the reviewed studies demonstrate that land use change, CSA, and food security are interconnected through dynamic synergies, trade-offs, and feedback loops. While unsustainable land-use changes often create negative cycles of degradation and food insecurity, CSA interventions can generate positive feedbacks that promote sustainable land use, ecosystem restoration, agricultural productivity, and climate resilience. The evidence underscores the importance of integrated landscape approaches that maximize synergies, minimize trade-offs, and strengthen positive feedback mechanisms to achieve sustainable food systems in SSA.

Research gaps and future research priorities

The synthesis of the selected studies reveals a growing body of evidence on the interlinkages among land use change, CSA (CSA), and food security in SSA (SSA). However, significant knowledge gaps remain that limit a comprehensive understanding of these interactions and constrain the development of effective policies and interventions. Addressing these gaps is essential for advancing sustainable land management, climate resilience, and food security across the region. One of the most prominent research gaps is the limited integration of land use change, CSA, and food security within a single analytical framework. Most researchers examine these themes independently or focus on only two components of the nexus. While several researchers assess the impacts of land use change on agricultural productivity, and others evaluate CSA adoption and food security outcomes, relatively few investigate how land use dynamics, CSA interventions, and food security interact simultaneously within coupled socio-ecological systems. In future studies, researchers should adopt integrated systems approaches that capture the complex interdependencies and feedback mechanisms among these variables. A second gap relates to the scarcity of longitudinal and spatially explicit studies. Much of the current evidence is derived from cross-sectional surveys and localized case studies, which limit the ability to assess long-term impacts and temporal dynamics. There is insufficient understanding of how land use changes evolve over time and how CSA interventions influence landscape transformations under different climate scenarios. In future studies, researchers should utilize remote sensing, Geographic Information Systems (GIS), and longitudinal datasets to analyze spatio-temporal patterns of land use change and their implications for food security.

Another important gap concerns the limited evaluation of trade-offs and unintended consequences of CSA interventions**.** Although CSA is widely promoted as a "triple-win" strategy for productivity,

adaptation, and mitigation, evidence on potential trade-offs remains fragmented. For example, agroforestry may temporarily reduce land available for annual crops, while conservation agriculture may require labor and financial investments that are inaccessible to resource-poor households. Thus, researchers should systematically assess economic, social, and environmental trade-offs associated with CSA adoption across agroecological and socioeconomic contexts. The review also reveals a lack of comparative studies across agroecological zones and farming systems**.** Most researchers focus on specific locations or production systems, making it difficult to generalize findings across SSA. There is limited evidence on how CSA effectiveness varies among arid, semi-arid, humid, and sub-humid regions, or among crop-based, livestock-based, and mixed farming systems. Comparative multi-country studies are needed to identify context-specific and scalable CSA solutions. Furthermore, social inclusion dimensions remain underexplored. Gender, youth participation, land tenure security, indigenous knowledge, and social equity issues are often treated as peripheral considerations rather than central determinants of land use decisions and CSA adoption. In future studies, researchers should investigate how social and institutional factors influence access to climate-smart technologies, land resources, and food security outcomes, particularly among vulnerable populations. The review also highlights limited evidence on the role of emerging digital and technological innovations in transforming land-use systems and food security. Technologies such as artificial intelligence, precision agriculture, remote sensing, climate information services, digital advisory platforms, and blockchain-enabled supply chains are increasingly being promoted across SSA. However, empirical evidence regarding their effectiveness, scalability, and implications for sustainable land use remains scarce. Future research should evaluate how these innovations can support climate adaptation, land restoration, and resilient agrifood systems. Finally, there is a need for stronger research on policy coherence and governance mechanisms**.** Researchers rarely examine how agricultural, environmental, climate, and land-use policies interact to influence CSA adoption and food security outcomes. In future studies, researchers should explore governance frameworks, institutional arrangements, and financing mechanisms that can facilitate integrated landscape management and sustainable development. Conclusively, researchers should prioritize interdisciplinary, multi-scale, and systems-based approaches that integrate environmental, economic, technological, and social dimensions. Such efforts will generate the evidence required to design effective strategies that maximize synergies, minimize trade-offs, and strengthen the resilience of land-use systems and food security under climate change in SSA.

4. Conclusions

In this scoping review, we synthesized evidence on the interlinkages among land use change, CSA (CSA), and food security under climate change in SSA (SSA). This scoping review demonstrates that climate change, land-use transformation, CSA, and food security are closely interconnected in SSA. Agricultural expansion, deforestation, land degradation, intensification, and landscape fragmentation characterize ongoing land-use transformations, with important implications for agricultural productivity, ecosystem services, and food security. Although expansion of cultivated land may provide short-term production gains, continued conversion and degradation of natural ecosystems can undermine the resource base required for long-term food production and climate resilience. CSA provides an important pathway for addressing these challenges. Agroforestry, conservation agriculture, integrated soil fertility management, improved water management, climate-resilient crop varieties, and sustainable intensification can enhance productivity and resilience while improving soil and ecosystem conditions. However, their effectiveness varies across agroecological and socioeconomic contexts, and adoption may be constrained by land, labor, finance, knowledge, and delayed economic returns. The

findings therefore support a shift from isolated farm-level interventions toward integrated and context-specific landscape approaches. Policies should prioritize CSA practices suited to local agroecological conditions, strengthen agricultural extension and climate-information services, improve smallholder access to affordable finance and productive inputs, and provide incentives for restoring degraded land and conserving forests and other natural ecosystems. Land-use planning should explicitly integrate agricultural production, climate adaptation, biodiversity conservation, and food-security objectives to minimize competing demands for land. Investment in research, monitoring, and spatially explicit evidence is also needed to identify where CSA can generate the greatest productivity, resilience, and conservation benefits. Finally, achieving climate-resilient food security in SSA requires policies that simultaneously enhance agricultural productivity, strengthen smallholder adaptive capacity, restore degraded landscapes, and reduce pressure for further conversion of natural ecosystems.

5. Limitations of the study

This scoping review has some limitations that should be considered when interpreting the findings. First, despite a comprehensive search strategy, only 17 studies met the predefined eligibility criteria. Although this reflects the limited body of research simultaneously examining the interrelationships among land-use change, CSA (CSA), climate change, and food security in SSA (SSA), the relatively small evidence base limits the extent to which findings can be generalized across the region's diverse farming systems and agroecological conditions. Second, the geographical distribution of the available evidence was uneven, with some countries and agroecological zones receiving greater research attention than others. Consequently, the findings may not have fully captured context-specific dynamics across all SSA countries. Third, substantial heterogeneity existed among the included studies in terms of research designs, analytical approaches, indicators of land-use change, CSA interventions, and measurements of food-security outcomes. This heterogeneity constrained direct comparison across studies and precluded quantitative synthesis or meta-analysis. Fourth, the review was restricted to studies published between 2000 and 2025 and accessible through the selected databases and literature sources; therefore, some relevant unpublished or non-indexed evidence may have been missed. Finally, many included studies examined individual or pairwise relationships among land use, CSA, and food security rather than the complete nexus, while limited longitudinal and spatially explicit evidence restricted assessment of long-term feedback mechanisms. Researchers should therefore employ integrated, longitudinal, and spatially explicit approaches to strengthen understanding of these interconnected processes across diverse SSA contexts.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The author of this study declares that there is no conflict of interest

Author contributions

Conceptualization: A.K.; methodology: A.K.; software: A.K.; validation: A.K. and T.O.O; formal analysis: A.K. and T.O.O.; investigation: A.K. and T.O.O.; resources: A.K. and T.O.O.; data curation:

A.K. and T.O.O.; writing–original draft preparation: A.K.; writing–review and editing: A.K. and T.O.O.; visualization: A.K. and T.O.O.; supervision: A.K. and T.O.O.; project administration: A.K. and T.O.O.; funding acquisition: A.K. and T.O.O. All authors have read and agreed to the published version of the manuscript.

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