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Land degradation and the upper hand of sustainable agricultural intensification in sub-Saharan Africa - A systematic review

Meron Lakew Tefera[a,c,*], Alberto Carletti[b], Laura Altea[a,c], Margherita Rizzu[a,c], Quirico Migheli[a,c], Giovanna Seddaiu[a,c]

[a]*Department of Agricultural Sciences, University of Sassari, Italy*
[b]*Department of Civil, Environmental Engineering and Architecture, University of Cagliari, Italy*
[c]*Desertification Research Group, NRD, University of Sassari, Italy*

Abstract

Sub-Saharan Africa (SSA) faces severe land degradation, driven by a combination of human and natural factors. Deforestation, inadequate land management practices, and unsustainable farming methods are the primary causes. The historical trends reveal the impact of soil erosion and nutrient depletion on 70 % of the soil and 65 % of its total land area. Unchecked degradation poses a critical threat to economic growth and poverty reduction initiatives. The region's food security is intricately linked to the complex interplay between land degradation and a rapidly growing population. Escalating demand for agricultural resources raises concerns about the ability to meet the needs of SSA's population. The adoption of sustainable agricultural intensification practices (SIAP) emerges as a crucial strategy to address land degradation and enhance food security. SIAP involves innovative and ecologically sensitive techniques, such as agroforestry and organic farming, targeting to optimise resource use and minimise negative impacts on soil health. The interconnectedness between factors of land degradation, food security, and the contribution of SIAP underscores the urgency of adopting sustainable practices to ensure a balanced relationship between agricultural productivity and environmental conservation in SSA. While SIAP holds promise, challenges such as socio-economic barriers, low adoption rates, and contextual variations necessitate continuous support and well-designed policies for successful implementation.

Keywords: agriculture, food security, poverty, soil erosion, sustainable land management

1 Introduction

Land is an essential resource (IPCC, 2019) and land degradation is commonly defined as the deterioration of the productive capacity of land (AbdelRahman, 2023; Pacheco *et al.*, 2018). Land degradation stands out as one of the most persistent and pressing global challenges (Stocking, 2001). Sub-Saharan Africa (SSA) accounts for 20 % of the value of ecosystem services of the terrestrial biomes and 16 % of the world's land area (Nkonya *et al.*, 2008; Nkonya *et al.*, 2016). The region accounts for 14.97 % of the world population in 2022 (UN, 2022) and is expected to account for 35 % by 2100 (Ezeh *et al.*, 2020). Smallholder farms account for more than 80 % of all farms, and farmers provide up to 90 % of the food supply in the region (Goedde *et al.*, 2019; Hlophe-Ginindza *et al.*, 2021). However, the region bears the most considerable portion (22 %) annual cost of land degradation in the world (Nkonya *et al.*, 2016). The world's most serious land degradation has been occurring in SSA during the past ten years (Byaro *et al.*, 2023). Unsustainable agricultural practices and deforestation are the leading causes (Zingore *et al.*, 2015). Nearly 70 % of the region's soil resources are affected by soil erosion and nutrient depletion (Nkonya *et al.*, 2008). 40 % of the soils in SSA are characterised by low nutrient reserves (Tully *et al.*, 2015), which is attributed to low suitability for agricultural production. The demand for adequate, cheap, and nutritious food in the region is being challenged by land degradation (Giller, 2020). As a consequence of degradation and climate change by 2050, about 86 million people will tend to migrate within

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[*] Corresponding author – mltefera@uniss.it

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their own countries making it the region with the highest number of internal refugees (WBG, 2021). Furthermore, the negative impacts of land degradation on human society are likely to become more prevalent, and undoubtedly SSA will be among the most affected areas by these impacts (Nkonya *et al.*, 2016).

Responding to these challenges, researchers have increasingly focused on sustainable agricultural intensification practices (SIAP) in recent years. This shift reflects the recognition of the pressing need for effective solutions to mitigate the consequences of land degradation. Civil society organisations, governments, and nongovernmental programs are also a part of this approach in SSA (M. A. Hossain *et al.*, 2021). SIAP has been reported to improve sustainable production (Kansiime *et al.*, 2021), increase natural capital (Pretty *et al.*, 2014), and help smallholder farmers to achieve higher yields on the same amount of land (Kassie *et al.*, 2015; Oumer *et al.*, 2020). Simultaneously, sustainable agricultural intensification serves as a vital strategy for reducing the strain on natural resources (Dalezios, 2017; Yahaya *et al.*, 2018) and enhancing the resilience of agricultural systems in SSA, where dependence on natural resources for livelihoods is pronounced.

In SSA, there is a notable gap in the literature regarding the relationship between land degradation and food security. While various studies exist on this topic, a comprehensive synthesis is lacking, particularly in evaluating the effectiveness of sustainable agricultural intensification practices in addressing land degradation and improving food security. Moreover, limited exploration of the factors hindering the contribution of these practices to addressing land degradation further underscores the need for a systematic review. Addressing this gap, this study aims to provide a comprehensive summary of existing literature on the topic, focusing on assessing the impact of sustainable agricultural intensification practices as a solution to combat land degradation and improve food security in SSA. Specifically, this research endeavours: a) Review and evaluate the current state of land degradation in SSA, examining indicators, causes, and impacts; b) Assess the effectiveness of sustainable agricultural intensification practices in mitigating land degradation and their implications for food production systems in the region; and c) Identify factors limiting the contribution of SIAP to addressing land degradation in SSA, offering insights to inform strategies for overcoming these constraints.

2 Methodology

This systematic review methodology involved structured approach to identify, select, critically appraise, and synthesize relevant research studies aligned with our objectives. It involved predefined criteria for study selection, systematic search strategies across multiple databases, transparent data extraction processes, and quality assessment of included studies.

2.1 Search strategy

The search strategy for this review was meticulously developed to ensure a systematic and focused approach. It involved selecting key terms, specifying databases, setting a publication timeframe, and applying selection criteria based on relevance and methodology. These inclusion/exclusion criteria encompassed factors such as relevance to the research question, publication type, date, geographic scope, language, intervention/exposure, and outcome measures aligned with the research objective. Following the Problem, Intervention, Comparison, Outcome (PICO) framework paradigm, the essential concepts and relevant scientific literature related to the research goal were identified, articles with the potential to answer the research questions were selected (Aromataris *et al.*, 2014), and components suitable for achieving optimal results were determined (Cumpston *et al.*, 2020; Foo *et al.*, 2021; Mengist *et al.*, 2020). The framework also guided decisions regarding the time range for the review, databases searched, search techniques employed, and methodologies for data extraction and analysis, ensuring a comprehensive and robust synthesis of the literature.

2.2 Search terms and strings

The scientific literature search was conducted using Web of Science and Google Scholar as primary sources. Furthermore, official reports and databases international research organisations including, the Food and Agriculture Organization (FAO), United Nations Conventions to Combat Desertification (UNCCD), European Soil Data Centre (ESDAC), International Centre for Tropical Agriculture (ICTA), and Consultative Group on International Agricultural Research (CGIAR) addressing similar findings aligned with the research objectives were consulted and reviewed to ensure comprehensive coverage. To streamline the search process, keywords, and connectors were employed systematically. The following lists detail the keywords and connectors utilised during the search: land degradation, sustainable intensification, SSA, AND erosion OR climate change OR soil fertility OR natural resource management, OR agroforestry OR soil conservation OR conservation agriculture (CA) OR pull-push OR zero tillage OR soil conservation OR water conservation OR manure OR organic fertilizer OR compost OR desertification OR water harvesting OR deforestation

OR overgrazing OR salinisation OR alkalisation OR soil compaction OR poor land management OR continuous cultivation OR land OR degradation OR intensification OR sustainability. Additionally, advanced search tools of the Web of Science were used to refine the search following the categories: environmental science, environmental studies, plant science, green, and sustainable technology, water resources, agronomy, remote sensing, forestry, agricultural economics, and policy.

2.3 Overview of the structure and typology of the reviewed paper

The examined papers were distributed across 25 countries within SSA, the general distribution accounts for 47 % of West Africa (Benin, Burkina Faso, Cape Verde, Ivory Coast, Ghana, Mali, Niger, Nigeria, Senegal and Togo), 31 % of East Africa (Djibouti, Ethiopia, Eritrea, Kenya, Malawi, Mozambique, Rwanda, Tanzania and Uganda), 16 % of Southern Africa (Namibia, South Africa and Zimbabwe), and 6 % of Central African countries (Cameroon, The DR of the Congo). More than 80 % of the articles were published after the year 2010. The publications search related to the topic of smallholder farmers at different scales yielded publications focusing on field and farm scales, as well as watershed scales, encompassing both qualitative and quantitative empirical studies, along with mixed findings at the land scale. However, articles not clearly expressing and referring to the topic and the search terms were excluded from the result. These data were then assessed for objectives, components, outcomes, requirements, and limitations and were extracted solely from a total of 143 shortlisted articles (Fig. 1). The extracted data were then analysed and synthesised to address the research question, with findings interpreted in context.

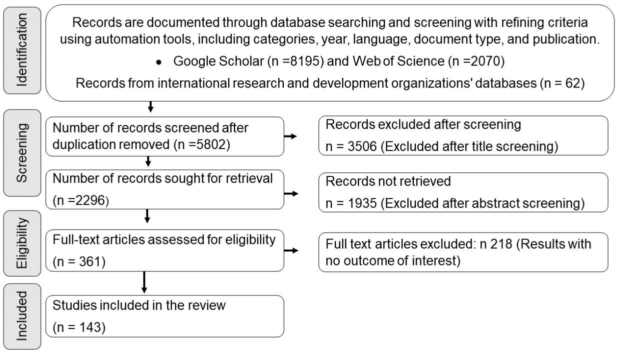

Fig. 1: *Study flow diagram (adopted from Page et al. (2021))*

3 Results

3.1 Land degradation and food security in sub-Saharan Africa

3.1.1 Land degradation in sub-Saharan Africa

Land degradation in SSA is an issue, impacting rural livelihoods and environmental stability (Nkonya *et al.*, 2008). According to different scholars, 60 to 73 % of Africa's topsoil is degraded; 24 % of which is due to agricultural practices, 49 % to overgrazing, 13 % to overexploitation, and 14 % due to deforestation particularly for fuelwood (Verso, 2015). The significant percentages highlight the various human activities contributing to the degradation of topsoil. Moreover, soil erosion washed away 60 % of topsoil, which ultimately ended up in rivers, streams, and lakes. which escalates the risk of flooding and increasing pesticide and fertilizer runoff, thereby contaminating water bodies (Mulvihill, 2021). This difficulty poses a substantial challenge to enhancing the sustainability of agricultural systems, particularly within SSA (Annappa *et al.*, 2023; Wakweya, 2023). Alarming predictions indicated that by 2020, over 75 % of SSA's arable land had been expected to be degraded (Snapp *et al.*, 2018), with projections suggesting that by 2050, as much as 90 % would be at risk (UNCCD, 2022). Fig. 2 illustrates extensive land degradation across Southern Africa, Southeastern, Eastern, Partly Western, and Central African regions, depicted in white to signify absence and black to indicate presence (Nkonya *et al.*, 2016).

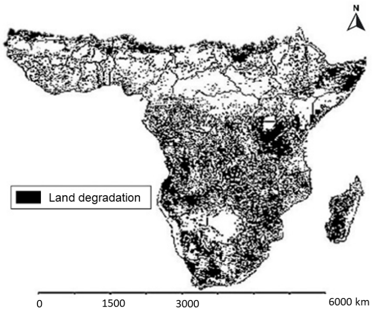

Fig. 2: *Extent of land degradation in SSA, adopted from Nkonya et al. (2016) and Gibbs et al. (2015).*

Land degradation in SSA is a multifaceted issue with significant environmental, social, and economic implications (Eni, 2012). Natural factors such as climate variability and extreme weather events, combined with human activities like deforestation, unsustainable agricultural practices, and urbanisation, contribute to the degradation of land and natural resources in the region (Becerril-Piña *et al.*, 2021; Pelser *et al.*, 2000). The consequences of land degradation are far-reaching, affecting food security, water resources, biodiversity, and the livelihoods of millions of people who depend on the land for their sustenance. Understanding the root causes and major impacts of land degradation is crucial for sustainable land and natural resource management (Morales *et al.*, 2019). To visually support the preceding discussion, Fig. 3 presents a summary of the main driving factors and adverse impacts of land degradation in SSA (Qi *et al.*, 2020).

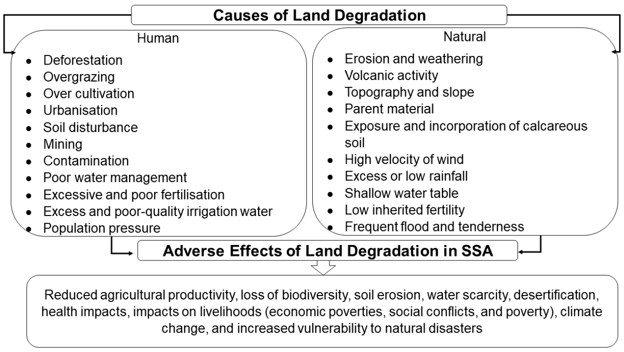

Fig. 3: *Summary of driving factors and impacts of land degradation in SSA (Compiled by the Author).*

3.1.2 Land degradation and food security in sub-Saharan Africa

The fundamental issue of food security in SSA is intricately linked to the complex interplay between land degradation and the region's rapidly growing population (Weldeghaber *et al.*, 2006). The demand for agricultural resources and land (FAO, 2022), driven by population growth of around 3 % per annum (UNEP, 2015). Agriculture, a cornerstone of SSA's economy, is crucial for ensuring food security (Claire, 2014; Utuk, 2015), mainly for small farms (El-Ramady *et al.*, 2014; Kavoi *et al.*, 2014). It is well reported that growth generated by agriculture is several times more effective in reducing poverty than growth in other sectors in SSA (Claire, 2014). However, intensive agricultural practices have led to substantial soil fertility decline in various parts of the region (Gupta, 2019). 39 % of households in SSA are classified as severely food insecure (Fraval *et al.*, 2019), and the region faces four times more land degradation than any other global area (Bjornlund *et al.*, 2022; FAO, 2017). This degradation exacerbates the challenge of feeding a growing population and intensifies the strain on natural resources, including increased demand for fuelwood (Maja *et al.*, 2021), leading to land degradation, desertification, climate change and subsequent food insecurity (Frelat *et al.*, 2016). Deforestation driven by agriculture significantly contributes to greenhouse gas (GHG) emissions in SSA, with the majority originating from land-use change, forestry, and the agricultural sector as of 2020. This sector alone accounts for approximately 43 % of CO_2 emissions in SSA. Poverty, greenhouse gas emissions, and land degradation are interconnected challenges, each exacerbating the other in a complex cycle of environmental and socioeconomic vulnerability. Despite strides in agricultural research and development efforts to improve yields and incomes, these impacts and their interconnectedness have not been commonly realised (Thornton *et al.*, 2011). The failure to prioritize sustainable food production, rural welfare, land protection, and soil fertility regeneration could perpetuate a cycle of food insecurity in SSA for years to come.

3.2 Land degradation: A comprehensive review of indicators, causes, and impacts

3.2.1 Land degradation indicators

In the realm of understanding land degradation, indicators emerge as pivotal tools, offering specific, measurable metrics to evaluate the land's health and track changes over time. These indicators, highlighted in numerous studies (FAO, 2003), not only serve as early warning signs but also provide crucial information for monitoring, analysis, and decision-making. However, the widespread use of indicator-based methodologies is not without conflicting perspectives (Kairis *et al.*, 2014), particularly concerning their application in monitoring land degradation (Morales *et al.*, 2019). The selection and interpretation of indicators demand caution, considering the diverse local conditions and underlying relationships influencing land degradation. Indicators, instead of simply indicating deterioration or progress, may authentically spotlight variations in the natural condition (FAO, 2003). Previous research has employed a spectrum of indicators to gauge land degradation, encompassing aspects related to soil water (Imbrenda *et al.*, 2013), land cover (Abdelfattah, 2009; Al-Awadhi *et al.*, 2005; Kosmas *et al.*, 2014), vegetation (Sharma, 1998), hydrology, runoff, sediment yield (Vanmaercke *et al.*, 2011), and groundwater resources (Eswaran *et al.*, 2019). Some studies even delve into the use of implemented regulations or policies as indicators of resource development and ecological sustainability, acknowledging their protective role against degradation (Salvati *et al.*, 2016). The literature further uncovers that indicators reflecting human pressure, institutional factors, social dynamics, and tourism contribute to assessing land vulnerability (Kosmas *et al.*, 2014; Pace *et al.*, 2023). Table 2 serves as a comprehensive summary, outlining the most prevalent factors and indicators of land degradation derived from existing research. Factors are variables that contribute to a phenomenon or situation. They are often broad categories that involve various aspects. Each factor has multiple indicat-

Table 1: *Summarizes factors and indicators of land degradation in agricultural land of sub-Saharan Africa.*

Factor	*Indicator*	*Citation*
Climate	Air temperature, rainfall, aridity index, potential evapotranspiration, and rainfall seasonality & erosivity (Extreme weather, too much or too little rainfall, high precipitation - soil erosion, drought - low rainfall amount, flooding – sedimentation).	(Sharma, 1998; Sivakumar *et al.*, 2007; Webb *et al.*, 2017; WMO, 2005)
Water and water use	Quality and quantity, groundwater exploitation, water demand, irrigation %, runoff water storage, water consumption per sector and water scarcity (low salinity, sodium adsorption ratio, conductivity, decreased area of water bodies, advanced runoff, declined groundwater resources, reduction in recharge rate in the hydrological area, reduction in surface, runoff volume, irrigation land area, and water consumption/year).	(EU, 2018; Noble, 2012; Nyssen *et al.*, 2009; Oliveira *et al.*, 2021; Pereira, 2005)
Soil	Drainage, parent material, rock fragments, slope aspect, soil texture, water storage capacity, and organic matter content, reduction or restricted segregation of soil elements the depth of hyrdomorphic features (Fe, Mn waterlogging, lack of oxygen and affects groundwater depth, compaction, decreased rainwater infiltration, redaction in the amount of water stored in soil & availability for plant growth, landfilling & accelerated soil erosion, flooding of low land and bedrock exposure on the soil surface, wind and water erosion, reduction in % of plant material, salinisation, land productivity).	(Akbari *et al.*, 2020; ESDAC, 2020; Eswaran *et al.*, 2019; EU, 2018; Nelson, 2009; Noble, 2012; Nyssen *et al.*, 2009; Oliveira *et al.*, 2021; Pereira, 2005; Sharma, 1998; Sivakumar *et al.*, 2007)
Vegetation	Effective land use and urban area, vegetation cover type, plant cover, grazing intensity & deforested area, land abandonment, land-use intensity, period of existing land use and fire frequency, fire risk, a burned area, & fire protection (Vegetation loss, Increase the application of fertilizers and pesticides, decreased land productivity, land use land cover change, overgrazing and uncontrolled grazing, deforestation, and low protection).	(Barbier *et al.*, 2018; Bensel, 2008; Bishaw *et al.*, 2013; Borrelli *et al.*, 2020; Dimobe *et al.*, 2015; Sengupta, 2013)
Land management and water runoff	Drainage density, flooding frequency, impervious surface area, reclamation of affected areas, soil erosion control measures, soil water conservation measures and terracing presence/absence (length of streams, size of water bodies, changes in land use, urbanisation, soil sealing, industry, transport, and waste disposal, deteriorated groundwater resources, erodible soil, flooding of low-land and dam sedimentation).	(Gardner *et al.*, 2009; Gessesse *et al.*, 2014; Kairis *et al.*, 2014; Kosmas *et al.*, 2014; Niang *et al.*, 2015; Sharma, 1998; Stroosnijder, 2007; Zainuddin, 2023).
Agricultural and cultivation-related	Farm ownership, farm size, parallel employment, net farm income, tillage (operations, frequency, depth, directions), mechanisation index (A decline in total land in hector and total income from the farm for each family, Soil disturbance and compaction tillage depth and frequency, Soil erosion, intensified agriculture and cultivation practices with slopping, waterlogging- mechanisation related to soil disturbance and compaction, monocropping and excessive use of agrochemicals).	(Akbari *et al.*, 2020; Hossain *et al.*, 2020; Mortimore, 1993; Priya, 2021; Salvati, 2011; Salvati *et al.*, 2016; Wolde *et al.*, 2021)
Social	Human poverty index, aging index, population density, growth rate, and distribution (Low level of human pressure on natural resources and farm income, increases population that impacts long-term sustainability of natural resources).	(Barbier *et al.*, 2018; Baye, 2017; Mortimore, 1993; Salvati, 2011; Salvati *et al.*, 2016; Taddese, 2001; Wolde *et al.*, 2021)
Institutional	Subsidies, protected areas, and policy enforcement, access to market (Low and unsustainable restoration works, low level of biodiversity conservation and cultural heritage, and the absence of agricultural and land-use policies).	(Chapman *et al.*, 2019; Ding *et al.*, 2021).
Tourism	Tourism intensity and tourism change (Soil erosion, pollution, natural habitat damage, and endangered species).	(Ekonomou *et al.*, 2023; Sahota, 2016; Ştefănică *et al.*, 2021).

ors that help assess and measure diverse aspects within that broader theme. Understanding both factors and indicators is crucial for gaining insights into the complex dynamics of land degradation, as factors provide the overarching framework within which indicators operate, helping to identify the root causes and drivers of degradation.

3.2.2 The underlying causes and impacts of land degradation on sub-Saharan Africa's agriculture

The extent of land degradation in SSA may vary across studies (Gomiero, 2016), but the underlying factors and impacts consistently mirror global patterns. A study by Tindwa *et al.* (2023) demonstrates that 36 out of the 80 countries affected by soil degradation worldwide are located in SSA. This comprehensive review identifies causes ranging from improper agricultural practices to deforestation and institutional challenges, revealing the intricate nature of the issue. Supported by extensive data, the impacts include concerns such as soil acidity, nutrient loss, and declines in vegetation cover (Qi *et al.*, 2020). Alarming statistics reveal significant percentages of land affected by water and wind erosion, deforestation, as well as improper irrigation practices, driving changes in the landscape that negatively affect land quality and functionality. Extensive research on Table 3 highlights the extent and severity of these impacts. On average, approximately 39.9 % of land in SSA experiences low nutrient capital reserves, and 45 to 67 % of the land is affected by desertification, while over 25 % of SSA's productive lands are degraded due to mining activities. Identified causes of land degradation impacts signify observable consequences, providing insights into the severity and extent of environmental, ecosystem, biodiversity, and human well-being changes. Regional disparities highlight the urgency of addressing these challenges, and the review emphasizes the interconnectedness between land degradation and societal well-being, citing issues like food insecurity, low income, and biodiversity loss. Table 3 serves as a valuable resource to identified causes of land degradation in SSA and serving as a valuable tool for decision-making, policy development, and advocacy efforts aimed at promoting sustainable land management practices and environmental conservation. The meticulous citation of sources enhances the 15 cited paper's credibility, forming a robust foundation for subsequent research and policy interventions.

3.3 Sustainable agricultural intensification to combat land degradation and food insecurity in sub-Saharan Africa

3.3.1 Sustainable agricultural intensification practices: implications for land degradation and food production systems in SSA

In SSA, agriculture plays a crucial role in sustaining the food and income of smallholder farmers (Bilsborrow, 1992). However, poor farming practices often lead to land degradation and resource loss (Struik *et al.*, 2017). SIAP emerges as a promising strategy for enhancing land productivity amidst degradation, addressing both food production increase and environmental challenges associated with land degradation in the region (UNDP, 2022). SIAP enhances environmental health (Fischer *et al.*, 2020) and increases economic benefit from the unit of land (Piñeiro *et al.*, 2020). Practices like agroforestry, crop rotation, soil conservation, organic farming, integrated soil fertility management (ISFM), water harvesting, conservation agriculture (CA), and climate-smart agriculture are widely recognised for improving land productivity (Giller *et al.*, 2020; Kuyah *et al.*, 2019; Mwaura *et al.*, 2021; Olarinde *et al.*, 2012; Wawire *et al.*, 2021; Wolka *et al.*, 2018). Specific SIAP practices such as ISFM and CA improve biodiversity, increase soil water infiltration by over 44 %, reduce runoff by 30 %, and minimize soil erosion by 33 % (Kihara *et al.*, 2020). Additionally, SIAP replenishes soil and other natural resources like water and air, ensuring sustainable food production systems and supporting ecosystem maintenance (FAO, 2023). Furthermore, SIAP reduces climatic vulnerability and desertification. A study spanning from 1999 to 2007 highlights SIAP's significant impact on drought reduction (Knutson *et al.*, 2011), while a survey in southern Africa's Chi-Nyanja Triangle demonstrates SIAP's ability to enhance land productivity even under climate change (Makate *et al.*, 2017). Further studies indicate that implementing SIAP enhances productivity, supports ecosystem preservation, strengthens adaptation to climate change, extreme weather, drought, and flooding, and improves land and soil quality over time (Sieber *et al.*, 2015). SIAP technologies also reduce reliance on forest resources, energy, pesticides, and inorganic fertilizers while managing greenhouse gas emissions through eco-friendly methods and nature-based solutions (Ahmadpour, 2016; Milestad *et al.*, 2003; Wang, 2009). Further demonstrated by Kim *et al.* (2021), citing three studies, when implementing CA, the emissions of nitrous oxide (N2O) per unit of crop yield are significantly reduced, ranging from 19 % to 88 % lower compared to conventional practices. Although, studies show that farmers can adapt to environmental changes using agronomic strategies at the crop, farm, and landscape levels (Dubey *et al.*, 2020).

Over the next five decades, there will be an increasing need to address land degradation, particularly soil health, and to secure land and water resources for food production (Zdruli *et al.*, 2010). Sustainable agriculture plays a crucial role in enhancing productivity despite land degradation (Ussiri *et al.*, 2019). However, the synthesis of 47 articles result on table 4 shows that the adoption rates and yield impacts of sustainable agricultural practices in SSA vary widely, ranging from 0.8 % to 68 %, and 3.7 % to 81 %, re-

Table 2: *A comprehensive overview of the identified causes of land degradation in sub-Saharan Africa (SSA), their impacts on agricultural land, and the extent of affected land as estimated by various scholarly sources.*

Identified causes of land degradation	*Impacts on agricultural land and its extent (Estimated affected land in %) in SSA*	*Citation*
Improper agricultural practices and Soil loss by water and wind, poor land management, and Insufficient use of organic inputs.	Impacts: Soil acidity & alkalinity toxicity, physical degradation loss of soil nutrients, loss of topsoil, nutrient depletion, and decreased water-holding capacity. Decline of soil properties - physio-chemical and biological properties, increased fertilizer uses and poor agricultural productivity, high soil erosion, soil fertility deterioration/ organic matter content, high soil erosion. Extent: Soil erosion- 46 % by water and 38 % wind erosion, unsustainable agricultural practices (24 %). - irrigation (4.5 % salinisation of cropland) and a decline in agricultural productivity of 2–40 %.	(Kirui *et al.*, 2014; Tamene *et al.*, 2015; Tindwa *et al.*, 2023; Tully *et al.*, 2015; Vlek *et al.*, 2010; Zingore *et al.*, 2015)
Deforestation (Uncontrolled Charcoal, land cleaning and wood production) and Overgrazing,	Impacts: Land degradation, land use/ land cover change, decline in vegetation cover, salinisation, soil erosion/soil loss and nutrient depletion, dropping in rainfall amount and distribution, deterioration of soil nutrients, loss of biodiversity, declining vegetative health, loss of habitat, poor agricultural productivity. Extent: 67 % of land because of deforestation SSA - About 51 % in Tanzania, 41 % in Malawi, 23 % in Ethiopia, and 22 % in Kenya, only between the 1982 and 2006 periods. (16 %) and 24 %,15 %,18 %, and 10 % in light, moderate, severe, and very severe by severity level, and in some cases in worse condition and beyond reclamation. 50 % overgrazing of all soil degradation in semi-arid and arid areas of Africa.	(Bot *et al.*, 2000; Kelatwang *et al.*, 2006; Vlek *et al.*, 2008)
Population density, expansion and intensification of agriculture, Land cover change/ Urbanisation/ Infrastructural expansion	Impacts: Physical surface selling, soil compaction, chemical -nutrient depletion, dispersion (alkalisation, toxic contaminations & salinisation), biological- depletion in organic matter, loss of biodiversity, and depletion of plant, animal, and microbial biomass, relocated rural residents, food insecurity and low nutritional levels, low household incomes, and poverty low rate of fertilizer use. Extent: 39.94 % of land in SSA goes through low nutrient capital reserves, 24.94 % al toxicity, 6.70 % calcareous reaction, and 2.21 % alkalinity, respectively.	(Tully *et al.*, 2015; Vlek *et al.*, 2010)
Extreme weather (Desertification), Topography, and slope.	Impacts: Soil erosion and, soil nutrient depletion, stagnant or declining agricultural productivity, Unproductive lands, and Reduced plant growth. Extent: Between 45 % and 70 % of all land is impacted by desertification, with approximately 20 % of this being severely degraded agricultural land.	(Nkonya *et al.*, 2008; Obalum *et al.*, 2012)
Institutional, Governance, and land tenure insecurity	Impacts: Biodiversity loss, soil fertility decline, food insecurity, low income, and low adoption of sustainable land management practices. Extent: 28 % of the land and 22 % of people are living/farming on degraded land.	(Nkonya *et al.*, 2016)
Mining	Impacts: Contamination, depletion of soil organic matter, accelerated erosion, acidification, salinisation and lack of plant nutrients, loss of nutrients and soil organic carbon, food and nutritional insecurity, and environmental degradation. Toxic chemicals and heavy metals leached from abandoned waste rock and tailings contaminate soil surfaces and groundwater. Extent: >25 % of SSA's productive lands degraded.	(Jones, 2013; Tindwa *et al.*, 2019; Tindwa *et al.*, 2023)

spectively, depending on the specific approach implemented and adoption. This variation is largely influenced by the diversity of practices implemented, such as agroforestry, conservation agriculture, organic farming (Pretty *et al.*, 2011), soil conservation measures, and water harvesting technologies. Tailoring these practices to the specific needs, ecological conditions, and socio-economic contexts of each region is essential for maximizing their effectiveness and ensuring successful implementation. At first, adoption trends in SSA are encouraging if they are backed by incentives, empirical sustenance, and information access. A study revealed that 53 % of the technology adoption is influenced by the

Table 3: *Sustainable agricultural intensification approaches' role and signs of adoption in SSA, compiled by author and adopted from Pedro et al. (2020).*

Approaches	*Practices*	*Impacts on land degradation and productivity*	*Countries*	*Signs of adoption and yield impact in SSA*	*Citation*
Agroforestry	Trees on farmland Scattered trees Alley cropping Windbreak and shelterbelts Home gardens Silvopastoral systems Multipurpose trees Plantation-crop combinations	Reduce deforestation (Source of fuel, fodder, and food products Reduce overgrazing as a source of animal fodder. Minimize soil erosion- Improve soil cover and groundwater recharge. Supplying habitat for associated species. Additional income - lower poverty.	Burkina Faso, Ethiopia, Benin, Ghana, Niger, Nigeria, Mali, Senegal, South Africa	Positive (+) • An estimated 1.2 billion individuals rely on it. 5 million ha of cropland with a mixed cropping system. Increased livestock product yields by 68 %. • Mean yield impact - 68 to 81 %.	(Arslan *et al.*, 2022; Chamshama *et al.*, 2009; Dobermann *et al.*, 2020; Duguma *et al.*, 2018; Franzel *et al.*, 2001; Iiyama *et al.*, 2014; Kuyah *et al.*, 2021; Kuyah *et al.*, 2019; Sheppard *et al.*, 2020; Zerihun, 2020)
Conservation agriculture (CA)	Minimal tilling (minimum soil disturbance) Permanent soil cover Crop rotation and (or intercropping with legumes) Mulching with crop residues	Improve soil organic matter - improve agronomic performance. Protect agroecosystems. Reduce soil erosion and soil compaction by tillage. Improve family nutrition (legumes to cereal) and income. Reduce fertilizer cost and impacts of climate change. Improve nutrient intake of the plant and enhance food security.	Benin, Botswana, Burkina Faso, Cameroon, Côte d'Ivoire, Ethiopia, Eritrea, Ghana, Lesotho, Malawi, Mali, Namibia, Niger, Nigeria, Sudan, Tanzania, Uganda, Zimbabwe	Positive (+) • Adopted – 0.8 to 1 % In 933 studies from 16 countries, the average yields > conventional tillage. Decrease soil erosion (28–500 %) and runoff (28–50 %). Improve soil cover. Decrease GHG emissions. • Mean yield impact - 3.7 to 37.6 %.	(Assefa *et al.*, 2020; Chinseu *et al.*, 2021; Corbeels *et al.*, 2015; Descheemaeker, 2020; Galani *et al.*, 2021; Kim *et al.*, 2021; Salustro, 2016; Wekesah *et al.*, 2019)
Organic farming (OM)	Biological pest and disease control Crop rotation, mechanical weed control Leguminous crops (nitrogen fixation) Green manure crops Use of compost/ organic manure	A healthy food production system and sustainable soil health imply people's health. Sustainable ecosystems - Reduce GHG emissions, improved ecological processes, biodiversity, Boost productivity & farm income, decrease poverty and hunger by 2030(Prediction). A study (Ghana & Kenya) has shown 292 % increase in gross margins and over 144 % higher yields compared to conventional farms.	Most SSA countries Benin, Ethiopia, Ghana, Kenya, Nigeria, Mali, Malawi, and Tanzania, Uganda	Positive (+) • Adoption - 11 to 68 % Adoption rate (13 to 68 % 127–308 % yield for coffee, and maize in Ghana & Kenya. 11 % income per capita, 55 % reduction household food gap. • Mean yield impact – 8 % and 78 %.	(Arslan *et al.*, 2022; Daadi *et al.*, 2021; Giller *et al.*, 2020; Kuyah *et al.*, 2019; Milestad *et al.*, 2003; Mwaura *et al.*, 2021; Schader *et al.*, 2021; Wei, 2020)
Soil conservation measures (SWC)	Agronomic, vegetative, structural, and management measures, like strip crops, terraces, contour. Soil and stone bunds Planting pits (zaï or Tassa) Bunds, slop barriers, cross-slope farming, vegetable covers, etc.	Reduce runoff velocity and soil erosion and reduce soil loss. Direct impact on crop yields due to the retention of nutrients and moisture and improve soil health. Normalize water flows. Boost soil biodiversity & greenhouse gases and influence ecosystem services positively. Increasing infiltration (>44).	Burkina Faso, Ethiopia, Ghana, Kenya, Mali, Niger, West Africa	Positive (+) • Adoption - 25.4 to 64 %. increases total crop yield by 17-24 % per household. 22-33 % income in smallholders. Reduce runoff by 13 –71 % and soil loss by 39 –83 %. > 86 % of studies found increased yield with nutrients and moisture. • Mean yield impact – 7 to 66 %.	(Abdulai *et al.*, 2013; Asfaw *et al.*, 2018; Bashir *et al.*, 2017; Judith, 2011; Kihara *et al.*, 2020; Olarinde *et al.*, 2012; Reij *et al.*, 2009; Reij *et al.*, 2010; Stewart *et al.*, 2020; Tilahun, 2019; Wolka *et al.*, 2018)
Water harvesting technologies (WHT)	Zai pits (*In situ* reservoir water harvesting techniques). Securing more rainwater and storing it (improving water accessibility) Using the available water (increasing water productivity)	Improve the water-holding capacity of soil. Overcoming droughts (water for families, livestock, and crops will have a greater chance). Reduce soil loss. Improved yields and helped a change to high-value crops. Recharge groundwater. Water retention in farmers' fields improved. alleviate water stress and enrich soil fertility. Enhancing food security and livelihood.	Burkina Faso, Ethiopia, Kenya, Niger, South Africa, Sudan, Rwanda, Zimbabwe, Tanzania	Positive (+) • Adoption – 3 to 67 %. 16.5 % sorghum and 9 % labor -Burkina Faso. 17-106 and 12-30 % in income - Ethiopia. Ndiva (Tanzania) – increase yield 22 and Food security 70 % and Zaï, grass strips, and bunds in Burkina Faso - 100–200 % yield and 70 % organic matter content. Increase productivity in 74-82 % Household ponds) Zai pits - 250 and 83 % (sorghum and maize yield). • Mean Yield impact – 12 % and 84 % increase in yield, depend on the SWC type	(Bouma *et al.*, 2012; Critchley *et al.*, 2013; Gebru *et al.*, 2020; Gowin *et al.*, 2013; ISPC, 2019; Karpouzoglou *et al.*, 2014; Kim *et al.*, 2021; Muchai *et al.*, 2020; Snelder *et al.*, 2018)

lack of empirical support related to information, wealth, social capital, and land tenure (Arslan *et al.*, 2022). The institutional arrangement, including access to inputs, finance, markets, and agricultural value chains to improve farm productivity and sustainability has been considered vital for implementing successful SIAP practices in SSA (Godfray *et al.*, 2014). This approach involves conducting thorough site assessments, understanding local farming practices, engaging with communities, and providing targeted technical support and resources to promote adoption and optimize yield impacts.

3.3.2 Sustainable agricultural intensification practices: addressing food insecurity in sub-Saharan Africa

Sustainable agricultural intensification practices are essential for combating land degradation and food insecurity in SSA, in line with global poverty eradication and ecosystem preservation goals (Martin *et al.*, 2018). Land degradation, caused by factors such as soil erosion, nutrient depletion, and loss of biodiversity, poses a significant threat to food security. Degraded soils have reduced fertility and water-holding capacity, leading to lower crop yields and food production. Additionally, land degradation can exacerbate food insecurity by reducing the availability of arable land for cultivation, increasing vulnerability to climate change, and undermining rural livelihoods. SIAP offers a multifaceted approach to improving land sustainability and enhancing food security (Smith *et al.*, 2020; Tittonell *et al.*, 2013). Agroforestry systems, for instance, promote biodiversity, enhance soil structure, nutrient content, water retention and soil fertility, and provide a buffer against climate variability (Garrity *et al.*, 2010). CA complements agroforestry by emphasizing minimal soil disturbance, cover cropping, and crop rotation (Gowing *et al.*, 2007), thereby contributing to improved soil health (Garrity *et al.*, 2010; Pretty *et al.*, 2011). Water harvesting technologies further enhance this synergy by capturing and efficiently utilizing rainwater for irrigation, mitigating water-related soil degradation (Rockström *et al.*, 2010). Concurrently, soil conservation measures, such as terracing and contour ploughing, prevent erosion and sustain overall soil integrity (Lal, 2001). Biological control and integrated plant protection, integral to organic farming, contribute to pest and disease management, aligning with the principles of ecological balance (Altieri *et al.*, 2003). Integrated soil fertility management reinforces these efforts by emphasizing nutrient cycling and organic matter incorporation, fostering sustained soil fertility (Pimentel *et al.*, 2005). Generally SIAP, with its focus on efficient resource use, plays a pivotal role in reducing land degradation by optimizing inputs (Kassam *et al.*, 2011). According to (Pretty *et al.*, 2011), from the 1990s to 2000s SIAP has been implemented in 20 SSA countries across more than 40 projects. The focus of these projects and programs were to implement eco-friendly technology and land management practices for sustainable intensification, promoting environmental conservation and increasing land productivity. The widespread implementation of SIAP across SSA countries in past decades reflects a growing recognition of the importance of sustainable agriculture in achieving food security and environmental sustainability. The interconnection of these practices within SIAP forms a holistic and synergistic approach that not only addresses land degradation but also promotes sustainable ecosystems, safeguarding the long-term productivity and health of the land. Similarly, recent study in Northwestern Ghana showed that community participation in SIAP reduced household access to food insecurity by 2.95 % (mean) compared to business-as-usual, with a decreasing amount of 11 % (Yahaya *et al.*, 2018). These practices, when strategically implemented, contribute to increased crop yields, subsequently addressing food insecurity concerns. Productivity is influenced by various factors, including the integration of different practices. Research suggests that the more these practices are integrated, the greater the potential yield advantage (Pretty *et al.*, 2011). This integration allows for synergies between different techniques, leading to improved soil health, nutrient retention, pest control, and overall crop resilience. The past success of SIAP initiatives suggests that there is potential for continued adoption and expansion of these practices in SSA (Table 4). By interconnecting sustainable agricultural intensification practices (Fig. 4), SSA can simultaneously improve land productivity, promote food security, and advance the region towards a sustainable agricultural future.

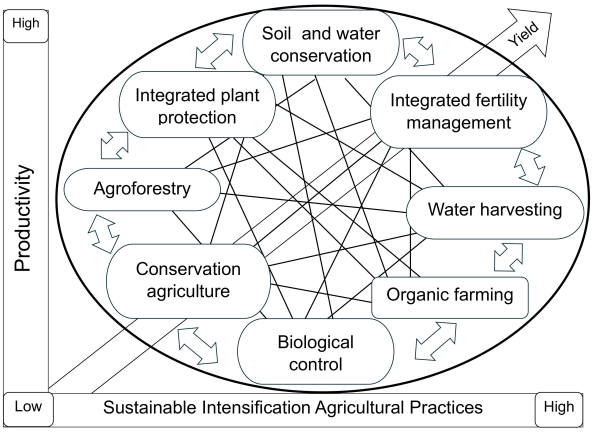

Fig. 4: *SIAP intervention impact on productivity and their interaction, the more these practices are integrated, the greater the potential yield advantage (compiled by the author).*

4 Discussion

4.1 *Balancing yield and conservation: Sustainable intensification of agriculture practices as a key solution in sub-Saharan Africa*

The factors contributing to land degradation in SSA are diverse and interconnected, spanning environmental, socio-economic, and institutional dimensions. Land degradation, food security, and the contribution of Sustainable Intensification of Agricultural Practices (SIAP) to enhancing land sustainability are all interdependent, which highlights the complex interaction among agricultural productivity, environmental well-being, and food availability. Shifting focus to SIAP in SSA is vital for addressing both land degradation and food insecurity. Agriculture being the primary source of food and income, improving production systems is crucial for enhancing food security. SIAP offers practical methods to boost land productivity despite degradation challenges, emphasizing innovative and eco-friendly techniques like agroforestry and organic farming. Practices such as crop rotation and cover cropping are highlighted for soil fertility restoration. Sustainable intensification maintains a balanced approach between productivity and environmental conservation, providing a practical solution to counteract land degradation. Adoption rates and yield impact data from SSA countries support the effectiveness of these practices (Bashir *et al.*, 2017; Gachene *et al.*, 2019). SIAP provides farmers with a promising opportunity to achieve better yields. The evidence from various reviewed studies emphasizes that SIAP is highly effective in enhancing soil quality, nutrient cycling, organic matter, soil carbon sequestration, moisture retention, temperature regulation, productivity, and nutritional value (Abbadiko *et al.*, 2018). Furthermore, farmers, in general, have gained valuable income and profits by implementing SIAP. The reviewed studies highlight the essential role of sustainable practices in promoting a healthy society and a better income (Osidoma *et al.*, 2021). Techniques like agroforestry and integrated soil fertility management continue to support native vegetation growth, facilitating natural processes and aiding in quick rebounds from environmental changes. SIAP not only contributes to healthier household diets but also ensures more sustainable agricultural productivity (Table 4). The interdependence between factors of land degradation, food security, and the contribution of SIAP to improving land sustainability is illustrated in Fig. 5.

4.2 *The concerned view - Factors limiting the contribution of sustainable intensification of agriculture practices to addressing land degradation*

Despite the promising potential of SIAP in bolstering agricultural sustainability, several obstacles hinder their effectiveness in addressing land degradation. Socio-economic barriers, low adoption rates, and inadequate implementation of SIAP techniques present significant challenges to achieving sustainable land management. Moreover, contextual variations in agroecological conditions and a lack of institutional support further complicate the success of SIAP across different regions. The literature point out the crucial role of robust policy frameworks in addressing declining agricultural production, natural resource depletion, and inappropriate land use in SSA. However, policymakers often overlook the importance of preserving land and soil health, which limits the conversion of native ecosystems to agricultural land. There is a pressing need for more studies and reliable data for accurate land degradation assessment, with a call for policy frameworks to support the contributions of land policy designers. Additionally, large-scale land degradation assess-

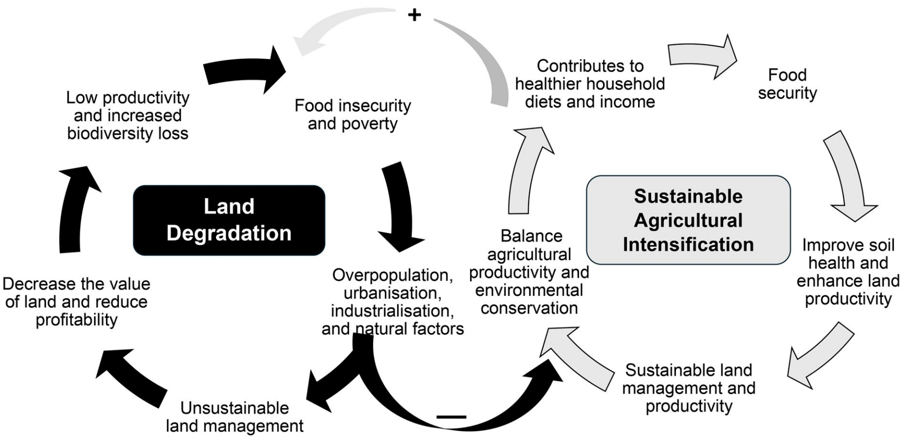

Fig. 5: *The interdependence between factors of land degradation, food security, and the contribution of SIAP to improving land sustainability, where darker colour indicates the negative impact and lighter colour the positive. (compiled by author).*

ment is deemed inaccurate due to several complex factors (Kopittke *et al.*, 2019; Mengist *et al.*, 2020; Ziadat *et al.*, 2021). The myriad challenges, including socio-economic barriers, low adoption rates, implementation gaps, contextual variations, insufficient institutional support, technological and educational gaps, market dynamics, and environmental variability, collectively underscore the complexity of promoting successful SIAP implementation in SSA. Continuous support for scaling up SIAP principles and practices (Mulale *et al.*, 2014), along with the creation of an enabling environment through well-designed policies and strategies, holds promise for sustainable land conservation in the region (Gomiero, 2016).

5 Conclusions

Failure to recognize the impacts of unsustainable natural resource management and land degradation without adhering to sustainability principles could have immediate repercussions on SSA agricultural production and ecosystem services. Therefore, it's imperative to take sustainable action to safeguard land and ensure an adequate food supply for the rapidly expanding population in SSA. This entails recognizing the consequences of land degradation, sharing knowledge and information with smallholder farmers, and implementing effective measures to tackle the issue. Additionally, tailoring SIAP is crucial to ensure their efficacy and applicability in diverse socio-economic and ecological contexts. This customisation enables the adaptation of agricultural techniques to specific local conditions, including soil types, climate patterns, and resource availability. By tailoring SIAP practices, stakeholders can effectively address the unique challenges and opportunities present in each region, thereby maximizing their positive impact on agricultural productivity, environmental sustainability, and food security. This review emphasizes the potential of SIAP in mitigating and reversing land degradation within the context of SSA.

6 A way forward

A comprehensive approach is needed to address the complex challenges of land degradation and food insecurity in SSA. This approach should encompass policy support and institutional strengthening to promote sustainable land management practices, coupled with capacity building and awareness initiatives to educate farmers about the benefits of adopting SIAP. Providing financial and technical support can help overcome barriers to SIAP adoption, while improving market access and value chain development can create economic opportunities for smallholder farmers. Research and innovation are essential for developing context-specific SIAP techniques that address the unique challenges faced in the region. By implementing these strategies in a coordinated manner, stakeholders can work towards overcoming the barriers to SIAP adoption and promoting sustainable land management practices, ultimately contributing to food security, environmental conservation, and rural livelihood improvement.

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Conflict of interest

The authors declare no competing interests.

References

Abbadiko, G. H., & Mulugeta, G. (2018). Sustainable Agriculture: Agroforestry for Soil Fertility and Food Security. *Journal of Equity in Sciences and Sustainable Development*, 44–53.

Abdelfattah, M. A. (2009). Land Degradation Indicators and Management Options in the Desert Environment of Abu Dhabi, United Arab Emirates. *Soil Horizons*, 50(1), 3–10. doi:10.2136/sh2009.1.0003.

AbdelRahman, M. A. E. (2023). An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications. Rendiconti Lincei. *Scienze Fisiche e Naturali*, 34(3), 767–808. doi: 10.1007/s12210-023-01155-3.

Abdulai, A., & Wallace, E. H. (2013). The Adoption and Impact of Soil and Water Conservation Technology: An Endogenous Switching Regression Application. *Land Economics*, 90(1), 26–43. doi:10.3368/le.90.1.26.

Ahmadpour, A. (2016). Effective factors on application of sustainable agricultural practices by paddy farmers (case of rural production cooperatives members). *International Journal of Agricultural Management and Development*, 6(1), 81–91. doi:10.22004/ag.econ.262540.

Akbari, M., Feyzi, K., Fateme, M., Hadi, A., Mahmud, A., & Noughani, M. A. (2020). Prioritizing effective indicators of desertification hazard using factor-cluster analysis, in arid regions of Iran. *Arabian Journal of Geosciences*, 13(8), 319. doi:10.1007/s12517-020-05296-9.

Al-Awadhi, J. M., Omar, S. A., & Misak, R. F. (2005). Land degradation indicators in Kuwait. *Land Degradation & Development*, 16(2), 163–176. doi:10.1002/ldr.666.

Altieri, M. A., & Nicholls, C. I. (2003). Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. *Soil and Tillage Research*, 72(2), 203–211. doi:10.1016/s0167-1987(03)00089-8.

Annappa, N. N., Bhavya, N., Govinda, K., Uday, K. S. N., & R. Krishna, M. (2023). Climate Change's Threat to Agriculture: Impacts, Challenges and Strategies for a Sustainable Future. In: Kamalvanshi, D. V., & Kushwaha, P. S. (Eds.). *Climate Change and Agriculture* (Volume - 9). Rohini, Delhi-110085, India: AkiNik Publications. pp. 113–136

Aromataris, E., & Riitano, D. (2014). Constructing a search strategy and searching for evidence. A guide to the literature search for a systematic review. *American Journal of nursing* , 114(5), 49–56. doi:10.1097/01.NAJ.0000446779.99522.f6.

Arslan, A., Floress, K., Lamanna, C., Lipper, L., & Rosenstock, T. S. (2022). A meta-analysis of the adoption of agricultural technology in Sub-Saharan Africa. *PLOS Sustainability and Transformation*, 1(7), 1–17. doi:10.1371/journal.pstr.0000018.

Assefa, T., Jha, M., Reyes, M., Worqlul, A. W., Doro, L., & Tilahun, S. (2020). Conservation agriculture with drip irrigation: Effects on soil quality and crop yield in sub-Saharan Africa. *Journal of Soil and Water Conservation*, 75(2), 209–217. doi:10.2489/jswc.75.2.209.

Barbier, E. B., & Hochard, J. P. (2018). Land degradation and poverty. *Nature Sustainability*, 1(11), 623-631. doi:10.1038/s41893-018-0155-4.

Bashir, S., Atif, J., Bibi, I., & Niaz, A. (2017). Soil and Water Conservation. In: Sabir, M., Javaid, A., & Hakeem, K. R. (Eds.). *Soil Science concepts and applications.* Pakistan University of Agriculture. Faisalabad, Pakistan. 12, 263–284.

Baye, T. G. (2017). Poverty, peasantry and agriculture in Ethiopia. *Annals of Agrarian Science,* 15(3), 420–430. doi:10.1016/j.aasci.2017.04.002.

Becerril-Piña, R., & Mastachi-Loza, C. A. (2021). Desertification: Causes and Countermeasures. In: Leal Filho, W., Azul, A., Brandli, L., Özuyar, P., Wall, T. (eds). *Life on Land. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham. pp. 1–13. doi:10.1007/978-3-319-71065-5_81-1

Bensel, T. (2008). Fuelwood, deforestation, and land degradation: 10 years of evidence from cebu province, the Philippines. *Land Degradation & Development*, 19(6), 587–605. doi:10.1002/ldr.862.

Bilsborrow, R. E. (1992). Population growth, internal migration, and environmental degradation in rural areas of developing countries. *European Journal of Population* , 8(2), 125–148. doi:10.1007/BF01797549.

Bishaw, B., Neufeldt, H., Mowo, J., Abdelkadir, A., Muriuki, J., Dalle, G., Assefa, T., Guillozet, K., Habtemariam, K., Dawson, I. K., Luedeling, E., & Mbow, C. (2013). Farmers' Strategies for Adapting to and Mitigating Climate Variability and Change through Agroforestry in Ethiopia and Kenya. *Forestry Communications Group, Oregon State University*, Corvallis, Oregon, USA. p. 96.

Bjornlund, V., Bjornlund, H., & van Rooyen, A. (2022). Why food insecurity persists in sub-Saharan Africa: A review of existing evidence. *Food Security*, 14(4), 845–864. doi:10.1007/s12571-022-01256-1.

Borrelli, P., Robinson, D. A., Panagos, P., Lugato, E., Yang, J. E., Alewell, C., Wuepper, D., Montanarella, L., & Ballabio, C. (2020). Land use and climate change impacts on global soil erosion by water (2015–2070). *Proceedings of the National Academy of Sciences of the United States of America* , 117(36), 21994–22001. doi:10.1073/pnas.2001403117.

Bot, A. J., Nachtergaele, F., & Young, A. (2000). Land resource potential and constraints at regional and country levels. *World Soil Resources Reports*. FAO. Rome, Italy. https://www.gbv.de/dms/goettingen/324575556.pdf.

Bouma, J., Critchley, W., & Barron, J. (2012). A review of the recent literature on water harvesting. In: Critchley, W. G. J. (Ed.), *Water Harvesting in Sub-Saharan Africa.* Taylor & Francis group . London.: Routledge. pp. 19. doi:10.4324/9780203109984.

Byaro, M., Nkonoki, J., & Mafwolo, G. (2023). Exploring the nexus between natural resource depletion, renewable energy use, and environmental degradation in sub-Saharan Africa. *Environmental Science and Pollution Research*, 30(8), 19931–19945. doi:10.1007/s11356-022-23104-7.

Chamshama, S. A. O., Nwonwu, F. O. C., Lundgren, B., & Kowero, G. S. (2009). Plantation Forestry in Sub Saharan Africa: Silvicultural, Ecological and Economic Aspects. *Discovery and Innovation*, 21(3), 169–176. doi:10.4314/dai.v21i3.48210.

Chapman, B., & Lindenmayer, D. B. (2019). A novel approach to the sustainable financing of the global restoration of degraded agricultural land. *Environmental Research Letters*, 14(12). doi:10.1088/1748-9326/ab5deb.

Chinseu, E. L., Dougill, A. J., & Stringer, L. C. (2021). Strengthening Conservation Agriculture innovation systems in sub-Saharan Africa: lessons from a stakeholder analysis. *International Journal of Agricultural Sustainability*, 20(1), 17–30. doi:10.1080/14735903.2021.1911511.

Claire, S.-C. (2014). Agricultural value chains in Sub-Saharan Africa: From a development challenge to a business opportunity. In M. L. Lanzeni (Ed.), Agricultural value chains in Sub-Saharan Africa: From a development challenge to a business opportunity. *Deutsche Bank Research*. Retrieved from https://www.dbresearch.com

Corbeels, M., Thierfelder, C., & Rusinamhodzi, L. (2015). Conservation Agriculture in Sub-Saharan Africa. In: Farooq, M., & Siddique, K. (Eds.), *Conservation Agriculture*. Springer, Cham., pp. 443–476.

Critchley, W., & Gowing, J. W. (2013). Water Harvesting in Sub-Saharan Africa (1 ed.). London: *Routledge- Taylor and Francis Group*. https://hdl.handle.net/10568/76775

Cumpston, M. S., McKenzie, J. E., Thomas, J., & Brennan, S. E. (2020). Current practice in systematic reviews including the ‘PICO for each synthesis’ and methods other than meta-analysis: protocol for a cross-sectional study. *F1000Research*, 9. doi:10.12688/f1000research.24469.1.

Daadi, B. E., & Latacz-Lohmann, U. (2021). Organic Fertilizer Adoption, Household Food Access, and Gender-Based Farm Labor Use: Empirical Insights from Northern Ghana. *Journal of Agricultural and Applied Economics*, 53(3), 435–458. doi:10.1017/aae.2021.8.

Dalezios, N. R. (2017). Environmental Hazards Methodologies for Risk Assessment and Management: Climate change and climate extremes. In: *Environmental Hazards Methodologies for Risk Assessment and Management*. London, UK: IWA.

Descheemaeker, K. (2020). Limits of conservation agriculture in Africa. *Nature Food*, 1(7), 402–402. doi:10.1038/s43016-020-0119-5.

Dimobe, K., Ouédraogo, A., Soma, S., Goetze, D., Porembski, S., & Thiombiano, A. (2015). Identification of driving factors of land degradation and deforestation in the Wildlife Reserve of Bontioli (Burkina Faso, West Africa). *Global Ecology and Conservation*, 4, 559–571. doi:10.1016/j.gecco.2015.10.006.

Ding, H., Anderson, W., & Zamora-Cristales, R. (2021). Smarter Farm Subsidies Can Drive Ecosystem Restoration. *world resource institute* Retrieved from https://connectedwomenleaders.com/smarter-farm-subsidies-can-drive-ecosystem-restoration/.

Dobermann, A., & Vanlauwe, B. (2020). Sustainable intensification of agriculture in sub-Saharan Africa: first things first. *Frontiers of Agricultural Science and Engineering*, 7(4), 376–382. doi:10.15302/j-fase-2020351

Dubey, P. K., Singh, G. S., & Abhilash, P. C. (2020). Adaptive Agronomic Practices for Sustaining Food Production. In: *Adaptive Agricultural Practices*, 1 ed., Springer Cham, pp. 11–43. doi:10.1007/978-3-030-15519-3_2

Duguma, L. A., Atela, J., Ayana, A. N., Alemagi, D., Mpanda, M., Nyago, M., Minang, P. A., Nzyoka, J. M., Foundjem-Tita, D., & Ngo Ntamag-Ndjebet, C. (2018). Community forestry frameworks in sub-Saharan Africa and the impact on sustainable development. *Ecology and Society*, 23(4). doi:10.5751/es-10514-230421.

Ekonomou, G., & Halkos, G. (2023). Is tourism growth a power of environmental‘de -degradation’? An empirical analysis for Eurozone economic space. *Economic Analysis and Policy*, 77, 1016–1029. doi:10.1016/j.eap.2022.12.029.

El-Ramady, H. R., Alshaal, T. A., Amer, M., Domokos-Szabolcsy, É., Elhawat, N., Prokisch, J., & Fári, M. (2014). Soil Quality and Plant Nutrition. *Sustainable Agriculture Reviews* 14, pp. 345–447. doi:10.1007/978-3-319-06016-3_11.

Eni, D. (2012). Effects of Land Degradation on Soil Fertility: A Case Study of Calabar South, Nigeria. *Environmental Land Use Planning* 18(1), pp. 166–171. doi:10.5772/51483

ESDAC. (2020). Land degradation. Retrieved 03/15/2022, from European Soil Data Center-European Commission https://esdac.jrc.ec.europa.eu/themes/land-degradation.

Eswaran, H., Lal, R., & Reich, P. F. (2019). Land degradation: An overview. In: Bridges, E. M. (Ed.), *Response to Land Degradation*, taylorfrancis.com, pp. 20–35.

EU. (2018). Land degradation: New EU measures for water reuse can help alleviate water scarcity and drought [Press release]. Retrieved from https://ec.europa.eu/info/news/land-degradation-new-eu-measures-water-reuse-can-help-alleviate-water-scarcity-and-drought-2018-jun-17_en.

Ezeh, A., Kissling, F., & Singer, P. (2020). Why sub-Saharan Africa might exceed its projected population size by 2100. *Lancet*, 396(10258), 1131–1133. doi:10.1016/S0140-6736(20)31522-1.

FAO. (2003). Data sets, indicators and methods to assess land degradation in drylands. *Fao archive.org* FAO, Rome, Italy. Retrieved from https://hdl.loc.gov/loc.gdc/gdclccn.2003380040.

FAO. (2017). The future of food and agriculture – Trends and challenges. *Food and Agriculture Organization of the United Nations*. http://www.fao.org/3/a-i6583e.pdf.

FAO. (2022). Prevalence of moderate or severe food insecurity in the population (%). (Report). Retrieved in 07/28/2022, *World Bank Group* https://data.worldbank.org/indicator/SN.ITK.MSFI.ZS.

FAO. (2023). Sustainable Development Goals. Food and Agriculture Organization, https://www.fao.org/sustainable-development-goals/indicators/241/en/.

Fischer, G., Darkwah, A., Kamoto, J., Kampanje-Phiri, J., Grabowski, P., & Djenontin, I. (2020). Sustainable agricultural intensification and gender-biased land tenure systems: an exploration and conceptualization of interactions. *International Journal of Agricultural Sustainability*, 19(5-6), 403–422. doi:10.1080/14735903.2020.1791425.

Foo, Y. Z., O'Dea, R. E., Koricheva, J., Nakagawa, S., & Lagisz, M. (2021). A practical guide to question formation, systematic searching and study screening for literature reviews in ecology and evolution. *Methods in Ecology and Evolution*, 12(9), 1705–1720. doi:10.1111/2041-210x.13654.

Franzel, S., Coe, R., Cooper, P., Place, F., & Scherr, S. J. (2001). Assessing the adoption potential of agroforestry practices in sub-Saharan Africa. *Agricultural Systems*, 69(1-2), 37–62. doi:10.1016/s0308-521x(01)00017-8.

Fraval, S., Hammond, J., Bogard, J. R., Ng'endo, M., van Etten, J., Herrero, M., Oosting, S. J., de Boer, I. J. M., Lannerstad, M., Teufel, N., Lamanna, C., Rosenstock, T. S., Pagella, T., Vanlauwe, B., Dontsop-Nguezet, P. M., Baines, D., Carpena, P., Njingulula, P., Okafor, C., Wichern, J., "…" & van Wijk, M. T. (2019). Food Access Deficiencies in Sub-saharan Africa: Prevalence and Implications for Agricultural Interventions. *Frontiers in Sustainable Food Systems*, 3. doi:10.3389/fsufs.2019.00104.

Frelat, R., Lopez-Ridaura, S., Giller, K. E., Herrero, M., Douxchamps, S., Andersson Djurfeldt, A., Erenstein, O., Henderson, B., Kassie, M., Paul, B. K., Rigolot, C., Ritzema, R. S., Rodriguez, D., van Asten, P. J., & van Wijk, M. T. (2016). Drivers of household food availability in sub-Saharan Africa based on big data from small farms. *Sustainability Science* , 113(2), 458–463. doi:10.1073/pnas.1518384112.

Gachene, C. K. K., Nyawade, S. O., & Karanja, N. N. (2019). Soil and Water Conservation: An Overview. In: *Zero Hunger*. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham. pp. 1–15. doi:10.1007/978-3-319-69626-3_91-1

Galani, Y. J. H., Ligowe, I. S., Kieffer, M., Kamalongo, D., Kambwiri, A. M., Kuwali, P., Thierfelder, C., Dougill, A. J., Gong, Y. Y., & Orfila, C. (2021). Conservation Agriculture Affects Grain and Nutrient Yields of Maize (*Zea mays* L.) and Can Impact Food and Nutrition Security in Sub-Saharan Africa. *Frontiers in Nutrition* , 8, 804663. doi:10.3389/fnut.2021.804663.

Gardner, R. A. M., & Gerrard, A. J. (2009). Relationships between runoff and land degradation on non-cultivated land in the Middle Hills of Nepal. *International Journal of Sustainable Development & World Ecology*, 9(1), 59–73. doi:10.1080/13504500209470103.

Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A., Larwanou, M., & Bayala, J. (2010). Evergreen Agriculture: a robust approach to sustainable food security in Africa. *Food Security*, 2(3), 197–214. doi:10.1007/s12571-010-0070-7.

Garzón Delvaux, P. A., Riesgo, L., & Gomez y P, S. (2020). Sustainable agricultural practices and their adoption in sub-Saharan Africa: A selected review. *JRC publication repository*, (JRC121035). Luxembourg: Publications Office of the European Union doi:10.2760/360761

Gebru, K. M., Woldearegay, K., van Steenbergen, F., Beyene, A., Vera, L. F., Kidane, T. G., & Alemayhu, T. (2020). Adoption of Road Water Harvesting Practices and Their Impacts: Evidence from a Semi-Arid Region of Ethiopia. *Sustainability*, 12(21). doi:10.3390/su12218914.

Gessesse, B., Bewket, W., & Bräuning, A. (2014). Model-Based Characterization and Monitoring of Runoff and Soil Erosion in Response to Land Use/land Cover Changes in the Modjo Watershed, Ethiopia. *Land Degradation & Development*, 26(7), 711–724. doi:10.1002/ldr.2276.

Gibbs, K, H., & Salmon, J. M. (2015). Mapping the world's degraded lands. *Applied Geography*, 57, 12-21.

Giller, K. E. (2020). The Food Security Conundrum of sub-Saharan Africa. *Global Food Security*, 26. doi.org/10.1016/j.gfs.2020.100431.

Giller, K. E., & Schut, A. G. T. (2020). Sustainable intensification of agriculture in Africa. *Frontiers of Agricultural Science and Engineering*, 7(4). doi:10.15302/j-fase-2020357.

Godfray, H. C., & Garnett, T. (2014). Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1639), 20120273. doi:10.1098/rstb.2012.0273.

Goedde, L., Ooko-Ombaka, A., & Pais, G. (2019). *Winning in Africa's agricultural market*. McKinsey & Company, 1–13. Retrieved from https://www.mckinsey.com/industries/agriculture/our-insights/winning-in-africas-agricultural-market.

Gomiero, T. (2016). Soil Degradation, Land Scarcity and Food Security: Reviewing a Complex Challenge. *Sustainability*, 8(3), 281.doi:10.3390/su8030281.

Gowin, J., & Bunclark, L. (2013). Water harvesting experience in sub-Saharan Africa - lessons for sustainable intensification of rainfed agriculture and the influence of available soils and rainfall data. Paper presented at the EGU General Assembly, Vienna, Austria. https://ui.adsabs.harvard.edu/abs/2013EGUGA..1513640G/abstract.

Gowing, J. W., & Palmer, M. (2007). Sustainable agricultural development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. *Soil Use and Management*, 24(1), 92–99. doi:10.1111/j.1475-2743.2007.00137.x.

Gupta, G. S. (2019). Land Degradation and Challenges of Food Security. *Review of European Studies*, 11(1). doi:10.5539/res.v11n1p63.

Hlophe-Ginindza, N. S., & Mpandeli, N. S. (2021). The Role of Small-Scale Farmers in Ensuring Food Security in Africa. In: *Food Security in Africa*: IntechOpen. doi:10.5772/intechopen.91694 pp. 1-14

Hossain, A., Krupnik, T. J., Timsina, J., Mahboob, M. G., Chaki, A. K., Farooq, M., Bhatt, R., Fahad, S., & Hasanuzzaman, M. (2020). Agricultural Land Degradation: Processes and Problems Undermining Future Food Security. In: Fahad, S., Hasanuzzaman, M., Alam, M., Ullah, H., Saeed, M., Ali Khan, I., & Adnan, M. (Eds.). *Environment, Climate, Plant and Vegetation Growth*. Springer, Cham. , pp. 17–61. doi:10.1007/978-3-030-49732-3_2

Hossain, M. A., Shrestha, S., Shrestha, A., Pandey, M., Subedi, S., Timsina, K. P., Subedi, S., & Shrestha, J. (2021). Sustainable Intensification in Agriculture: An Approach for Making Agriculture Greener and Productive. *Journal of Nepal Agricultural Research Council*, 7, 133–150. doi:10.3126/jnarc.v7i1.36937.

Iiyama, M., Neufeldt, H., Dobie, P., Njenga, M., Ndegwa, G., & Jamnadass, R. (2014). The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. *Current Opinion in Environmental Sustainability*, 6, 138–147. doi:10.1016/j.cosust.2013.12.003.

Imbrenda, V., Demilio, M., Lanfredi, M., Simoniello, T., Ragosta, M., & Macchiato, M. (2013). Integrated Indicators for the Estimation of Vulnerability to Land Degradation. In: Hernandez Soriano, M. C. (Ed.). *Soil Processes and Current Trends in Quality Assessment*. IntechOpen. doi:10.5772/52870.

IPCC. (2019). Climate Change and Land, an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Retrieved from https://ipcc.ch/report/srccl.

ISPC. (2019). How can Small-scale Farmers in Niger be Encouraged to Adopt Rainwater Harvesting? Results from a Pilot Study. Brief N. 74. Rome: *Independent Science and Partnership Council*. https://cas.cgiar.org/spia/publications/how-can-small-scale-farmers-niger-be-encouraged-adopt-rainwater-harvesting.

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M. and Le Roux. (2013). *Soil atlas of Africa*: European Commission. doi:10.2788/52319.

Judith, B., A. Oduol, J. Binam, L. Olarinde, A. Diagne, A. Adekunle. (2011). Impact of adoption of soil and water conservation technologies on technical efficiency: Insight from smallholder farmers in Sub-Saharan Africa. *Journal of Development and Agricultural Economics*, 3(14), 655–669. doi:10.5897/jdae11.091.

Kairis, O., Kosmas, C., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., Alcala, M., Alfama, P., Atlhopheng, J., Barrera, J., Belgacem, A., Sole-Benet, A., Brito, J., Chaker, M., Chanda, R., Coelho, C., Darkoh, M., Diamantis, I., Ermolaeva, O., Fassouli, V., "..." & Ziogas, A. (2014). Evaluation and selection of indicators for land degradation and desertification monitoring: types of degradation, causes, and implications for management. *Environmental Management* , 54(5), 971–982. doi:10.1007/s00267-013-0110-0.

Kansiime, M. K., Njunge, R., Okuku, I., Baars, E., Alokit, C., Duah, S., Gakuo, S., Karanja, L., McHana, A., Mibei, H., Musebe, R., Romney, D., Rware, H., Silvestri, S., Sones, D., & Watiti, J. (2021). Bringing sustainable agricultural intensification practices and technologies to scale through campaign-based extension approaches: lessons from Africa Soil Health Consortium. *International Journal of Agricultural Sustainability*, 20(5), 743–757. doi:10.1080/14735903.2021.1976495.

Karpouzoglou, T., & Barron, J. (2014). A global and regional perspective of rainwater harvesting in sub-Saharan Africa's rainfed farming systems. *Physics and Chemistry of the Earth, Parts A/B/C*, 72–75(75), 43–53. doi: 10.1016/j.pce.2014.09.009.

Kassam, A., Friedrich, T., Shaxson, F., & Pretty, J. (2011). The spread of Conservation Agriculture: justification, sustainability and uptake. *International Journal of Agricultural Sustainability*, 7(4), 292–320. doi:10.3763/ijas.2009.0477.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, 42, 400–411. doi: 10.1016/j.landusepol.2014.08.016.

Kavoi, J., Mwangi, J. G., & Kamau, G. M. (2014). Challenges faced by small landholder farmer regarding decision making in innovative agricultural development: an empirical analysis from Kenya. *International Journal of Agricultural Extension*, 02(02), 101–108.

Kelatwang, S., & Garzuglia, M. (2006). Changes in forest area in Africa 19902005. *International Forestry Review*, 8(1), 21–30. doi:10.1505/ifor.8.1.21.

Kihara, J., Bolo, P., Kinyua, M., Nyawira, S. S., & Sommer, R. (2020). Soil health and ecosystem services: Lessons from sub-Sahara Africa (SSA). *Geoderma*, 370(1). doi: 10.1016/j.geoderma.2020.114342.

Kim, D.-G., Grieco, E., Bombelli, A., Hickman, J. E., & Sanz-Cobena, A. (2021). Challenges and opportunities for enhancing food security and greenhouse gas mitigation in smallholder farming in sub-Saharan Africa. A review. *Food Security*, 13(2), 457–476. doi:10.1007/s12571-02101149-9.

Kirui, O. K., & Mirzabaev, A. (2014). Economics of land degradation in Eastern Africa. In: Tielkes, E. (ed.). *Tropentag 2014, Book of Abstracts*. pp. 490. 10.13140/2.1.1442.2400

Knutson, C. L., Haigh, T., Hayes, M. J., Widhalm, M., Nothwehr, J., Kleinschmidt, M., & Graf, L. (2011). Farmer perceptions of sustainable agriculture practices and drought risk reduction in Nebraska, USA. *Renewable Agriculture and Food Systems*, 26(3), 255–266. doi:10.1017/s174217051100010x.

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A., & Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environ Int*, 132, 105078. doi:10.1016/j.envint.2019.105078.

Kosmas, C., Kairis, O., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., Alcala, M., Alfama, P., Atlhopheng, J., Barrera, J., Belgacem, A., Sole-Benet, A., Brito, J., Chaker, M., Chanda, R., Coelho, C., Darkoh, M., Diamantis, I., Ermolaeva, O., Fassouli, V., "..." & Ziogas, A. (2014). Evaluation and selection of indicators for land degradation and desertification monitoring: methodological approach. *Journal of Environmental Management* , 54(5), 951–970. doi:10.1007/s00267-013-0109-6.

Kuyah, S., Sileshi, G. W., Nkurunziza, L., Chirinda, N., Ndayisaba, P. C., Dimobe, K., & Öborn, I. (2021). Innovative agronomic practices for sustainable intensification in sub-Saharan Africa. A review. *Agronomy for Sustainable Development*, 41(2). doi:10.1007/s13593-021-00673-4.

Kuyah, S., Whitney, C. W., Jonsson, M., Sileshi, G. W., Öborn, I., Muthuri, C. W., & Luedeling, E. (2019). Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis. *Agronomy for Sustainable Development*, 39(5). doi:10.1007/s13593-019-0589-8.

Lal, R. (2001). Soil degradation by erosion. *Land Degradation & Development*, 12(6), 519–539. doi:10.1002/ldr.472.

Maja, M. M., & Ayano, S. F. (2021). The Impact of Population Growth on Natural Resources and Farmers' Capacity to Adapt to Climate Change in Low-Income Countries. *Earth Systems and Environment*, 5(2), 271–283. doi:10.1007/s41748-021-00209-6.

Makate, C., Makate, M., & Mango, N. (2017). Smallholder Farmers' Perceptions on Climate Change and the Use of Sustainable Agricultural Practices in the Chinyanja Triangle, Southern Africa. *Social Sciences*, 6(1), 30. doi: 10.3390/socsci6010030.

Martin, A., Coolsaet, B., Corbera, E., Dawson, N., Fisher, J., Franks, P., Mertz, O., Pascual, U., Rasmussen, L. V., & Ryan, C. (2018). Land use inication promise of sustainability and the reality of trade-offs. In: *Ecosystem Services and Poverty Alleviation*. London, pp. 17.

Mengist, W., Soromessa, T., & Legese, G. (2020). Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX*, 7, 100777. doi:10.1016/j.mex.2019.100777.

Milestad, R., & Darnhofer, I. (2003). Building Farm Resilience: The Prospects and Challenges of Organic Farming. *Journal of Sustainable Agriculture*, 22(3), 81-97. doi:10.1300/J064v22n03_09.

Morales, N. S., & Zuleta, G. A. (2019). Comparison of different land degradation indicators: Do the world regions really matter? *Land Degradation & Development*, 31(6), 721–733. doi:10.1002/ldr.3488.

Mortimore, M. (1993). Population growth and land degradation. *GeoJournal*, 31(1), 15–21. doi:10.1007/BF00815897.

Muchai, S., Ngetich, F. K., Baaru, M., & Mucheru-Muna, W. (2020). Adoption and utilisation of Zai pits for improved farm productivity in drier upper Eastern Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 121(1), 13–22. doi:10.17170/kobra-202002281030.

Mulale, K., Chanda, R., Perkins, J. S., Magole, L., Sebego, R. J., Atlhopheng, J. R., Mphinyane, W., & Reed, M. S. (2014). Formal Institutions and Their Role in Promoting Sustainable Land Management in Boteti, Botswana. *Land Degradation & Development*, 25(1), 80-91. doi:10.1002/ldr.2274.

Mulvihill, K. (2021). Soil Erosion 101. *NDRC Data, Reports & Resources*. Retrieved from https://www.nrdc.org/stories/soil-erosion-101.

Mwaura, G. G., Kiboi, M. N., Bett, E. K., Mugwe, J. N., Muriuki, A., Nicolay, G., & Ngetich, F. K. (2021). Adoption Intensity of Selected Organic-Based Soil Fertility Management Technologies in the Central Highlands of Kenya. *Frontiers in Sustainable Food Systems*, 4. doi:10.3389/fsufs.2020.570190.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K., Daily, G.,Goldstein, J., Kareiva, P., Lonsdorf, E., Naidoo, R., Ricketts, T., & Shaw, M. (2009). Modeling multiple Ecosystem Services, biodiversity conservation, commodity production and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment*, 7(1), 4–11.

Niang, D., Yacouba, H., Doto, C. V., Karambiri, H., & Lahmar, R. (2015). Land Degradation Impact on Water Transfer of Soil plant-Atmosphere Continuum in the Burkinabe Sahel. *Larhyss-Environmental Science*, 24, 109–127.

Nkonya, E., John, P., Kayuki, C. K., Edward, K., Samuel, M., Henry, S., & James, M. (2008). *Linkages Between Land Management, Land Degradation, and Poverty in Sub-Saharan Africa, The Case of Uganda* (Vol. 159). Washington, D.C. U.S.A: International Food Policy Research Institute. pp. 1–122. doi:10.2499/9780896291683RR159.

Nkonya, E., Johnson, T., Kwon, H. Y., & Kato, E. (2016). Economics of Land Degradation in Sub-Saharan Africa. In: Nkonya, E., Mirzabaev, A., von Braun, J. (eds) *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*, Springer International Publishing. pp. 215–259. doi:10.1007/978-3-319-19168-3_9.

Noble, A. (2012). The slumbering giant: land and water degradation. Paper presented at the *The Scramble for Natural Resources: More Food, Less Land?*, Canberra, Australia. http://ageconsearch.umn.edu/record/152413.

Nyssen, J., Poesen, J., & Deckers, J. (2009). Land degradation and soil and water conservation in tropical highlands. *Soil and Tillage Research*, 103(2), 197–202. doi:10.1016/j.still.2008.08.002.

Obalum, S. E., Buri, M. M., Nwite, J. C., Hermansah, Watanabe, Y., Igwe, C. A., & Wakatsuki, T. (2012). Soil Degradation-Induced Decline in Productivity of Sub-Saharan African Soils: The Prospects of Looking Downwards the Lowlands with theSawahEcotechnology. *Applied and Environmental Soil Science*, 2012, 1–10. doi:10.1155/2012/673926.

Olarinde, L. O., Oduol, J. B., Binam, J. N., Diagne, A., Njuki, J., & Adekunle, A. A. (2012). Impact of the adoption of soil and water conservation practices on crop production: baseline evidence of the Sub Saharan Africa challenge programme . *Middle East Journal of Scientific Research*, 9(1), 28–40.

Oliveira, M. L., Dos Santos, C. A. C., de Oliveira, G., Perez-Marin, A. M., & Santos, C. A. G. (2021). Effects of human-induced land degradation on water and carbon fluxes in two different Brazilian dryland soil covers. *Science of the Total Environment*, 792, 148458. doi:10.1016/j.scitotenv.2021.148458.

Osidoma, J., & Kinkwa, A. M. (2021). *Creatively Improving Agricultural Practices and Productivity: Pro Resilience Action (PROACT) project, Nigeria.* A case study from the European Union and the Oxfam Pro-Resilience Action Project, pp. 1-8. doi:10.21201/2021.7260.

Oumer, A. M., Burton, M., Hailu, A., & Mugera, A. (2020). Sustainable agricultural intensification practices and cost efficiency in smallholder maize farms: Evidence from Ethiopia. *Agricultural Economics*, 51(6), 841–856. doi: 10.1111/agec.12595.

Pace, L., Imbrenda, V., Lanfredi, M., Cudlin, P., Simoniello, T., Salvati, L., & Coluzzi, R. (2023). Delineating the Intrinsic, Long-Term Path of Land Degradation: A Spatially Explicit Transition Matrix for Italy, 1960-2010. *International Journal of Environmental Research and Public Health*, 20(3). doi:10.3390/ijerph20032402.

Pacheco, F. A. L., Sanches, F. L. F., Valle Junior, R. F., Valera, C. A., & Pissarra, T. C. T. (2018). Land degradation: Multiple environmental consequences and routes to neutrality. *Current Opinion in Environmental Science & Health*, 5, 79–86. doi:10.1016/j.coesh.2018.07.002.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, 372, n71. doi:10.1136/bmj.n71.

Pelser, A. J. K. T. (2000). *Some causes and strategies pertaining to land degradation in southern Africa. South African.Journal of Agricultural Extension*, 29(1), 24-46. doi:10.4314/sajae.v29i1.3627.

Pereira, L. S. (2005). Combating Desertification: Water Conservation and Water Saving Issues. *Mediterranean Journal of Economics, Agriculture and Environment*, 4(1), 4–13.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., & Seidel, R. (2005). Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. *BioScience*, 55(7). doi:10.1641/0006-3568(2005)055[0573:Eeaeco]2.0.Co;2.

Piñeiro, V., Arias, J., Dürr, J., Elverdin, P., Ibáñez, A. M., Kinengyere, A., Opazo, C. M., Owoo, N., Page, J. R., Prager, S. D., & Torero, M. (2020). A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. *Nature Sustainability*, 3(10), 809–820. doi:10.1038/s41893-020-00617-y.

Pretty, J., & Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of Botany*, 114(8), 1571–1596. doi:10.1093/aob/mcu205.

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability* 9(1), 5-24. doi: 10.3763/ijas.2010.0583.

Priya, R. (2021). Land Degradation and Agricultural Productivity. In: *Land Degradation in India*. Springer Briefs in Environmental Science. Springer, Cham, pp. 93–100. doi:10.1007/978-3-030-68848-6_5.

Qi, Y., Bhunia, P., Zhang, T. C., Luo, F., Lin, P., & Chen, Y. (2020). Environmental Degradation and Sustainability. In: *Sustainability: Fundamentals and Applications*, Willy online library pp. 483–505.

Reij, C., Smale, M., & Tappan, G. G. (2009). Re-greening the Sahel: farmer-led innovation in Burkina Faso and Niger. In: Spielman, D. J., & Pandya-Lorch, R. (Ed.), *Millions fed: Proven successes in agricultural development*. International Food Policy Research Institute. pp. 53–58.https://pubs.usgs.gov/publication/70157359

Reij, C., Tappan, G., & Smale, M. (2010). Agroenvironmental transformation in the Sahel: Another kind of “Green Revolution" *International Food Policy Research Institute (IFPRI)*. p. 43.

Rockström, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., & Qiang, Z. (2010). Managing water in rainfed agriculture – The need for a paradigm shift. *Agricultural Water Management*, 97(4), 543–550. doi.org/10.1016/j.agwat.2009.09.009.

Sahota, K. K. (2016). Tourism and Environmental Degradation. *International Journal of Agriculture & Environmental Science*, 3(5), 1–3. doi:10.14445/23942568/ijaes-v3i5p101.

Salustro, M. (2016). Designing and implementing conservation agriculture in sub-Saharan Africa. In: *IFAD/Malawi – Sustainable Agricultural Production Programme (SAPP)*. Retrieved from https://www.ifad.org/documents/38714170/40195959/conservation_teaser.pdf/8945394f-1b9a-4863-84d8-1fd95df136a7.

Salvati, L. (2011). The spatial nexus between population growth and land degradation in a dry Mediterranean region: a rapidly changing pattern? *International Journal of Sustainable Development & World Ecology*, 19(1), 81–88. doi:10.1080/13504509.2011.593007.

Salvati, L., Kosmas, C., Kairis, O., Karavitis, C., Acikalin, S., Belgacem, A., Sole-Benet, A., Chaker, M., Fassouli, V., Gokceoglu, C., Gungor, H., Hessel, R., Khatteli, H., Kounalaki, A., Laouina, A., Ocakoglu, F., Ouessar, M., Ritsema, C., Sghaier, M., Sonmez, H., "..." & Carlucci, M. (2016). Assessing the effectiveness of sustainable land management policies for combating desertification: A data mining approach. *Journal of Environmental Management*, 183(Pt 3), 754–762. doi:10.1016/j.jenvman.2016.09.017.

Schader, C., Heidenreich, A., Kadzere, I., Egyir, I., Muriuki, A., Bandanaa, J., Clottey, J., Ndungu, J., Grovermann, C., Lazzarini, G., Blockeel, J., Borgemeister, C., Muller, A., Kabi, F., Fiaboe, K., Adamtey, N., Huber, B., Niggli, U., & Stolze, M. (2021). How is organic farming performing agronomically and economically in sub-Saharan Africa? *Global Environmental Change*, 70. doi:10.1016/j.gloenvcha.2021.102325.

Sengupta, R. (2013). Land Use and Land Degradation. In: *Ecological Limits and Economic Development*. Oxford Scholarship Online, pp. 155–182.

Sharma, K. D. (1998). The hydrological indicators of desertification. *Journal of Arid Environments*, 39(2), 121–132. doi:10.1006/jare.1998.0403.

Sheppard, J. P., Bohn Reckziegel, R., Borrass, L., Chirwa, P. W., Cuaranhua, C. J., Hassler, S. K., Hoffmeister, S., Kestel, F., Maier, R., Mälicke, M., Morhart, C., Ndlovu, N. P., Veste, M., Funk, R., Lang, F., Seifert, T., du Toit, B., & Kahle, H.-P. (2020). Agroforestry: An Appropriate and Sustainable Response to a Changing Climate in Southern Africa? *Sustainability*, 12(17). doi:10.3390/su12176796.

Sieber, S., Jha, S., Tharayil Shereef, A.-B., Bringe, F., Crewett, W., Uckert, G., Polreich, S., Ndah, T. H., Graef, F., & Mueller, K. (2015). Integrated assessment of sustainable agricultural practices to enhance climate resilience in Morogoro, Tanzania. *Regional Environmental Change*, 15(7), 1281–1292. doi:10.1007/s10113-015-0810-5.

Sivakumar, M. V. K., & Stefanski, R. (2007). Climate and Land Degradation – an Overview. In: *Climate and Land Degradation*: Springer, Berlin, Heidelberg, pp. 105–135.

Smith, P., Soussana, J. F., Angers, D., Schipper, L., Chenu, C., Rasse, D. P., Batjes, N. H., van Egmond, F., McNeill, S., Kuhnert, M., Arias-Navarro, C., Olesen, J. E., Chirinda, N., Fornara, D., Wollenberg, E., Alvaro-Fuentes, J., Sanz-Cobena, A., & Klumpp, K. (2020). How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology* , 26(1), 219–241. doi:10.1111/gcb.14815.

Snapp, S., Rahmanian, M., Batello, C., & Calles, T. (2018). Pulse Crops for Sustainable Farms in Sub-Saharan Africa. In: Calles.T (Ed). Rome, *Food and Agriculture Organization of the United Nations*, pp.1–36. doi:10.18356/6795bfaf-en.

Snelder, D., Kahimba, F., Korodjouma, O., Abebe, A., Oughton, E., Bunclark, L., & Lasage, R. (2018). Adaptations in Water Harvesting Technologies for Enhancing Food Security and Livelihood: A Multi-country Study in Sub-Saharan Africa. In: Filho, W. L. & de Trincheria Gomez, J. (Eds.), *Rainwater-Smart Agriculture in Arid and Semi-Arid Areas*. Switzerland: Springer International. pp. 95–119.

Ştefănică, M., Sandu, C. B., Butnaru, G. I., & Haller, A.-P. (2021). The Nexus between Tourism Activities and Environmental Degradation: Romanian Tourists' Opinions. *Sustainability*, 13(16). doi:10.3390/su13169210.

Stewart, Z. P., Pierzynski, G. M., Middendorf, B. J., & Prasad, P. V. V. (2020). Approaches to improve soil fertility in sub-Saharan Africa. *Journal of Experimental Botany*, 71(2), 632–641. doi:10.1093/jxb/erz446.

Stocking, M. A. (2001). Land Degradation. In: *International Encyclopedia of the Social & Behavioral Sciences*, pp. 8242–8247.

Stroosnijder, L. (2007). Rainfall and Land Degradation. In: *Climate and Land Degradation*, Berlin, Heidelberg: Springer, pp. 167–195.

Struik, P. C., & Kuyper, T. W. (2017). Sustainable intensification in agriculture: the richer shade of green. A review. *Agronomy for Sustainable Development*, 37(5). doi:10.1007/s13593-017-0445-7.

Taddese, G. (2001). Land degradation: a challenge to Ethiopia. *Journal of Environmental Management* , 27(6), 815–824. doi:10.1007/s002670010190.

Tamene, L., & Le, Q. B. (2015). Estimating soil erosion in sub-Saharan Africa based on landscape similarity mapping and using the revised universal soil loss equation (RUSLE). *Nutrient Cycling in Agroecosystems*, 102(1), 17–31. doi:10.1007/s10705-015-9674-9.

Thornton, P. K., Jones, P. G., Ericksen, P. J., & Challinor, A. J. (2011). Agriculture and food systems in sub-Saharan Africa in a 4 degrees C+ world. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* , 369(1934), 117–136. doi:10.1098/rsta.2010.0246.

Tilahun, A. (2019). Conservation and production impacts of soil and water conservation practices under different socioeconomic and biophysical setting: a review. *Journal of Degraded and Mining Lands Management*, 06(02), 1653–1666. doi:10.15243/jdmlm.2019.062.1653.

Tindwa, H. J., Semu, E., Shelukindo, H. B., & Singh, B. R. (2019). Soil Degradation with Reference to Nutrient Mining and Soil Fertility Decline in Sub-Saharan Africa. In: Lal R. & Stewart B. A. (Eds.), *Soil Degradation and Restoration in Africa*. Taylor & Francis ebooks, Boca Raton: 25–39. doi:10.1201/b22321.

Tindwa, H. J., & Singh, B. R. (2023). Soil pollution and agriculture in sub-Saharan Africa: State of the knowledge and remediation technologies. *Frontiers in Soil Science*, 2. doi:10.3389/fsoil.2022.1101944.

Tittonell, P., & Giller, K. E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, 143, 76–90. doi:10.1016/j.fcr.2012.10.007.

Tully, K., Sullivan, C., Weil, R., & Sanchez, P. (2015). The State of Soil Degradation in Sub-Saharan Africa: Baselines, Trajectories, and Solutions. *Sustainability*, 7(6), 6523–6552. doi:10.3390/su7066523.

UN. (2022). *World Population Prospects 2022: Summary of Results* (9789210014380). Retrieved from United Nations New York, 2022: https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf.

UNCCD. (2022). *Chronic land degradation*: UN offers stark warnings and practical remedies in Global Land Outlook 2. https://www.unccd.int/news-stories/press-releases/chronic-land-degradation-un-offers-stark-warnings-and-practical.

UNDP. (2022). *Africa sustainable development report, executive summary and key policy recommendations from AU/UNECA/ /AFDB/ UNDP*. https://www.undp.org/sites/g/files/zskgke326/files/2023-06/asdr_2022-en-full_report-final.pdf.

UNEP. (2015). *The Economics of Land Degradation in Africa: Benefits of Action Outweigh the Costs;A complementary report to the ELD Initiative*. Retrieved from Bonn, Germany: https://www.unep.org/resources/publication/economics-land-degradation-africa.

Ussiri, D. A. N., & Lal, R. (2019). Soil Degradation in Sub-Saharan Africa. In: Lal R. & Stewart B. A. (Eds.). *Soil Degradation and Restoration in Africa*. Taylor & Francis ebooks, Boca Raton: CRC Press, pp. 1–24. doi:10.1201/b22321-1.

Utuk, I. O., Ekong E. Daniel. (2015). Land Degradation: A Threat to Food Security: A Global Assessment. *Journal of Environment and Earth Science*, 5(8), 13–21.

Vanmaercke, M., Poesen, J., Maetens, W., de Vente, J., & Verstraeten, G. (2011). Sediment yield as a desertification risk indicator. *Science of the Total Environment* , 409(9), 1715–1725. doi:10.1016/j.scitotenv.2011.01.034.

Verso, E. (2015). Topsoil Erosion. *Stanford University* http://large.stanford.edu/courses/2015/ph240/verso2/.

Vlek, P. L. G., Le, Q. B., & Tamene, L. (2008). Land decline in land-rich Africa: a creeping disaster in the making. *Consultive Group on International Agricultural Research (CGIAR)* ; Universität Bonn https://edepot.wur.nl/481066.

Vlek, P. L. G., Le, Q. B., & Temene, L. (2010). Assessment of land degradation, its possible causes and threat to food security in Sub-Saharan Africa. In: Rattan Lal B. A. S. (Ed.), *Advances in Soil Science Food Security and soil quality*. Heidelberg, DE: CRC Press, pp. 57–86.

Wakweya, R. B. (2023). Challenges and prospects of adopting climate-smart agricultural practices and technologies: Implications for food security. *Journal of Agriculture and Food Research*, 14. doi:10.1016/j.jafr.2023.100698.

Wang, Y. W. (2009). Sustainable agricultural practices: energy inputs and outputs, pesticide, fertilizer and greenhouse gas management. *Asia Pacific Journal of Clinical Nutrition*, 18(4), 498–500.

Wawire, A. W., Csorba, A., Toth, J. A., Micheli, E., Szalai, M., Mutuma, E., & Kovacs, E. (2021). Soil fertility management among smallholder farmers in Mount Kenya East region. *Heliyon*, 7(3), e06488. doi:10.1016/j.heliyon.2021.e06488.

WBG. (2021). *Climate Change Could Force 216 Million People to Migrate Within Their Own Countries by 2050* (2022/12/CCG). Retrieved from Washington: https://www.worldbank.org/en/news/press-release/2021/09/13/climate-change-could-force-216-million-people-to-migrate-within-their-own-countries-by-2050.

Webb, N. P., Marshall, N. A., Stringer, L. C., Reed, M. S., Chappell, A., & Herrick, J. E. (2017). Land degradation and climate change: building climate resilience in agriculture. *Frontiers in Ecology and the Environment*, 15(8), 450–459. doi:10.1002/fee.1530.

Wei, C. (2020). Agroecology, Information and Communications Technology, and Smallholders' Food Security in Sub-Saharan Africa. *Journal of Asian and African Studies*, 55(8), 1194–1208. doi:10.1177/0021909620912784.

Wekesah, F. M., Mutua, E. N., & Izugbara, C. O. (2019). Gender and conservation agriculture in sub-Saharan Africa: a systematic review. *International Journal of Agricultural Sustainability*, 17(1), 78–91. doi:10.1080/14735903.2019.1567245.

Weldeghaber, K., & Materne, M. P., Dardel. (2006). *Food security and agricultural development in sub-Saharan Africa-Building a case for more public support*. Retrieved from https://www.fao.org/3/a0627e/a0627e.pdf.

WMO. (2005). *Climate and Land Degradation* (989). Retrieved from http://www.droughtmanagement.info/literature/WMO_climate_land_degradation_2005.pdf.

Wolde, Z., Wei, W., Ketema, H., Yirsaw, E., & Temesegn, H. (2021). Indicators of Land, Water, Energy and Food (LWEF) Nexus Resource Drivers: A Perspective on Environmental Degradation in the Gidabo Watershed, Southern Ethiopia. *International Journal of Environmental Research and Public Health*, 18(10). doi:10.3390/ijerph18105181.

Wolka, K., Mulder, J., & Biazin, B. (2018). Effects of soil and water conservation techniques on crop yield, runoff and soil loss in Sub-Saharan Africa: A review. *Agricultural Water Management*, 207, 67–79. doi:10.1016/j.agwat.2018.05.016.

Yahaya, I., Pokharel, K. P., Alidu, A.-F., & Yamoah, F. A. (2018). Sustainable agricultural intensification practices and rural food security. *British Food Journal*, 120(2), 468–482. doi:10.1108/bfj-01-2017-0021.

Zainuddin, P., D. D. A., Hadinata, F. (2023). The Effect of Land Degradation on Changes in Water Availability in Watershed Areas. In Proceedings of the 9th International Conference on Energy Engineering and Environmental Engineering (pp. 103-114).

Zdruli, P., Pagliai, M., Kapur, S., & Faz Cano, A. (2010). What We Know About the Saga of Land Degradation and How to Deal with It? In: Zdruli, P. , Pagliai, M., Kapur,S., & Faz Cano, A. (Eds.), *Land Degradation and Desertification: Assessment, Mitigation and Remediation*. Springer, Dordrecht, pp. 3–14. doi:10.1007/978-90-481-8657-0_1.

Zerihun, M. F. (2020). Institutional Analysis of Adoption of Agroforestry Practices in the Eastern Cape Province of South Africa. *Journal of Education*, 37–55. doi:10.4314/sajee.v36i1.9.

Ziadat, F. M., Zdruli, P., Christiansen, S., Caon, L., Monem, M. A., & Fetsi, T. (2021). An Overview of Land Degradation and Sustainable Land Management in the Near East and North Africa. *Sustainable Agriculture Research*, 11(1). doi:10.5539/sar.v11n1p11.

Zingore, S., Mutegi, J. K., Agesa, B. L., Tamene, L., & Kihara, J. (2015). Soil Degradation in sub-Saharan Africa and Crop Production Options for Soil Rehabilitation. *Better Crops with Plant Food*, 99(1), 24–26. https://hdl.handle.net/10568/68702.