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Reviving cropping land in Sub-saharan Africa: An in-depth review of the land recovery potential and strategies

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Abstract

Land degradation is a major challenge affecting the sustainability of agriculture and livestock production systems worldwide. Poor soil and water management practices coupled with unsustainable agricultural practices are known to accelerate land degradation. Globally, approximately 18.1 million km² of land is degraded, of which 62% is due to unsustainable use of the land and 38% is due to overgrazing. In Sub-Saharan Africa is 46% grassland, 12% cropland, and 26% forest land. This review found that SSA has a vast potential in restoring degraded land ranging from land degradation monitoring and evaluation, agricultural conservation techniques, soil biotechnology, and soil management techniques. The increasing land degradation problem in SSA is due to the ineffective utilization of soil conservation techniques. Effective utilization of land recovery potential and strategies in SSA for the aim of restoring degraded land in the region will play a large part in addressing the problem of land degradation which resulted in food insecurity in the SSA. This review recommends the following: the creation of participatory policies that allow governments to work successfully with local farmers to manage the soil sustainably using soil restoration and conservation technologies, making better and more effective use of the large informational resources from previously completed soil conservation and restoration based projects, continued funding of agricultural research to encourage the creation of technology that will restore degradation land and increase yields using sustainable land management practices, and need for the agent action to transform existing conventional agriculture into agricultural practices which ensure sustainability.

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Introduction

Land degradation is a major threat to the sustainability of agriculture and animal production systems around the world (Wynants *et al.*, 2019). Land degradation is influenced by poor soil and water management practices coupled with unsustainable agriculture (Chalise *et al.*, 2019). Land degradation is associated with a deterioration in the biological, chemical, and physical quality of soil, which affects the soil's capacity to deliver ecological services (Chabay, 2018; Tsatskin, 2021). In Sub-Saharan Africa approximately 65% of the total land is degraded (SSA) (Vlek *et al.*, 2008), which affects social-environmental systems, hydrological cycle, and biochemical processes (Fernando *et al.*, 2018). Due to its detrimental effects on agriculture, the environment, and food security, land degradation is a persistent problem throughout the world.

Globally, approximately 18.1 million km² of land is degraded of which 62% is due to unsustainable use of the land and 38% is due to overgrazing (Hamdy & Aly, 2014; Toor *et al.*, 2020). Generally, land degradation typically affects 20% of arable land, 30% of forests, and 10% of grazing area, which affects approximately 1.5 billion people (Pimentel, 2006). A study done by Reich *et al.*, (2001) in Africa reported that 22% and 25% of the land was disposed off to wind and water erosion respectively. Desertification affects up to 65% of the agricultural land on the African continent and about 39% of the continent overall (Hossain *et al.*, 2020). In Sub-Saharan Africa degraded land accounts for 46% of grassland, 12% of cropland, and 26% of forest land (Gebreselassie *et al.*, 2015). Bindraban *et al.*, (2012) and (Muoni *et al.*, 2019) found that 30% of the cropping land in SSA is degraded by soil erosion, nutrient mining, deforestation, and overgrazing.

It costs around 300 billion USD a year to manage land degradation in agricultural and pasture land due to changes in land use, land cover, and other factors (Braun *et al.*, 2013). The largest percentage (22%) of the total global cost of land degradation is covered by SSA. Farmers pay about 46% of the cost of land degradation brought on by Land Use Land Cover Changes, which is equivalent to 78% of the total cost of land degradation in the globe. Ecosystem consumers who do not use farms, like those who pay a high price for food crops, pay the remaining 54% (Nkonya *et al.*, 2015). This further demonstrates that, although having a significantly bigger impact on impoverished land users, land degradation is a global issue. Acting to stop land deterioration has tremendous benefits and is substantially less expensive than doing nothing. According to (Braun *et al.*, 2013), investing one dollar in restoring damaged land often yields five dollars in return. This offers a compelling reason to take action to stop land deterioration.

Unsustainable agricultural intensification has been cited as a major cause of land degradation that affects the soil health ecosystem, its ability to provide ecological services and decrease crop productivity. Due to agricultural intensification, each year about 24 million tonnes of topsoil are lost because of soil erosion. The projection shows that this may lead to 50 million people shifting from their current residence in the next 10 years (UNCCD, 2017). Hence, sustainable land management and restoration strategies can reduce and restore degraded land in the region. The main factors contributing to land degradation in the SSA include water erosion, salinization, loss of soil organic carbon, removal of vegetation, extinction of species, and settlement expansion. An effective approach for reducing and restoring degraded cropland in the SSA is the implementation of soil conservation techniques and sustainable land management practices. This review paper intends to explore land restoration potentials and strategies in the region specifically focusing on sustainable and innovative approaches to restoring degraded land.

Types and Causes of Land Degradation in Sub-Saharan Africa

Types of land degradation

Three types of land degradation exist in SSA; chemical, biological, and physical land degradation (Tully *et al.*, 2015). The major common types of land degradation are physical soil degradation in the form of water and wind erosion (Kiptoo & Mirzabaev, 2014). SSA has been observed to have a more serious problem with land degradation due to soil erosion than in non-tropical places (Sanchez & Swarninathan, 2009). Several factors have been put forth as to why the tropics experience such high rates of soil erosion, including the harsh climate, high soil erosivity, the prevalence of extremely fragile soils, steep slopes, insufficient land management, and, primarily, resource-poor farmers who cannot afford to implement conservation measures (Kiage, 2013). However, during the 1980s and 1990s, the first narrative that was widely known by policymakers and development organizations operating in SSA was that severe land degradation in the form of soil erosion was caused by ineffective land management brought on by ignorance and a lack of education (Kimaru & Jama, 2006).

Major causes of land degradation

Land degradation has been caused by anthropogenic factors, natural factors, or a combination of both. Some of the anthropogenic factors that cause land degradation are deforestation, vegetation cover loss, inadequate land use policies, and insufficient soil conservation interventions. Deforestation is the extensive clearing of forests for agriculture, urbanization, or logging resulting in the removal of vegetation cover (Tsegaye *et al.*, 2023). Forests protect the soil from erosion and help to stabilize it naturally. Deforestation disrupts this equilibrium and leaves the soil vulnerable to soil erosion, nutrient depletion, and reduced water-holding capacity (Mazi *et al.*, 2022; Moisa *et al.*, 2022). In addition to deforestation, other factors leading to loss of vegetation cover are overgrazing, unsustainable land use practices, and bush firing. Vegetation cover plays a significant role in reducing land degradation by acting as a physical barrier against water and wind forces. Insufficient vegetation cover accelerates soil erosion which leads to land degradation. Insufficient land use planning and implementation can also lead to land degradation. When land is utilized without taking into account its ecological capacities such as converting fragile ecosystems into agricultural land or urban areas, it accelerates soil erosion, lowers soil fertility, and interferes with the natural ecosystems that keep the soil healthy (Oliveira, 2018). The absence of effective soil conservation techniques aggravates land degradation. Without appropriate interventions like terracing, contour plowing, cover cropping, and erosion control structures, soil erosion intensifies, water runoff increases, and due to a loss of topsoil, soil fertility declines (Kumawat *et al.*, 2020).

Land degradation occurs through the interaction between human interaction and the biophysical environment. The process of soil erosion is greatly influenced by biophysical elements, such as the soil, climate, topography, and vegetation cover. For instance, the erodibility of soils is determined by the fundamental characteristics of soils, such as texture, structure, organic matter concentration, clay mineralogy, and water retention properties (Kiage, 2013). The rate of erosion is determined by topographic factors including slope steepness, length, and shape, whereas erosivity is influenced by rainfall features like intensity, amount, and frequency. Although these biophysical forces might interact to cause soil erosion, frequently need the involvement of human activities (Chalise *et al.*, 2019).

Land Degradation Assessment and Monitoring in SSA

Decision-makers need to monitor and prepare mitigation strategies for sustainable land management practices, which require assessment and monitoring of land degradation (Tesfahunegn *et al.*, 2011). More specifically, monitoring land degradation regularly allows decision-makers to understand the impact of land degradation and the effects of soil conservation techniques. To address this problem, effective techniques to evaluate and track land degradation are imperative for sustainability. Using this information, decision-makers set attainable management goals for example; to reach land degradation neutrality by 2030 as directed by the Sustainable Development Goal - SDG 15.

Land degradation is often measured by evaluating the status and trends using the productivity of agricultural land. However, as variables other than land degradation such as climate phenomena, precipitation, pests, and diseases can also affect productivity, this method is considered biased and imprecise. Hence, researchers have developed several techniques to quantify and assess land degradation, including the use of remote sensing, expert/land manager knowledge, and field measurements and observations (Omuto *et al.*, 2014).

Land Degradation Surveillance Framework (LDSF)

The LDSF is a geographically stratified, randomized sample technique that was developed to provide a landscape-level biophysical baseline and a framework for monitoring and evaluating land degradation processes and the effectiveness of restoration activities (Tor-gunnar *et al.*, 2013). LDSF provides a biophysical assessment and monitoring of the process of land degradation as well as the success of short- and long-term rehabilitation measures. It can also be used as part of a monitoring approach to detect vegetation changes over time (Lohbeck *et al.*, 2018). The technique typically produces maps of 16 indicators of land degradation, which help to evaluate the state of a landscape.

The World Agroforestry (ICRAF) created the LDSF to meet the demand for uniform field techniques and indicator frameworks to evaluate land health in landscapes. The technique was effectively established during land degradation studies in the Lake Victoria basin of Kenya, Mali, Southern Africa, and Madagascar. The framework is currently being used in projects all over the tropics and includes more than 30,000 observations, making it one of the largest land health databases worldwide (Lohbeck *et al.*, 2018).

To map the soil functional parameters and land degradation risk at a geographical scale of 500 m Vågen *et al.*, (2014) use data from 114 LDSF sites, which were collected between 2010 and 2013. As the foundation for focusing on sustainable land management techniques, Waswa *et al.* (2013) employ LDSF to assess the geographical and temporal patterns of indicators of land degradation. Kyei, (2020) uses the data collected using LDSF to complement qualitative data from farmers' perception of the study to assess the rate of land degradation in Kenya. In their study, Lohbeck *et al.*, (2018) used LDSF to discover that, above-ground biomass has a positive effect on soil health in East Africa by raising SOC and lowering soil erosion. In their study carried out in Ethiopia, Vågen *et al.*, (2013) integrated LDSF to produce predictive models and maps of several indicators of land health that could be used to develop management recommendations.

Its cost-effectiveness and less time demand are among the potential benefits of incorporating LDSF in the monitoring of land degradation and conservation strategies. Winowiecki *et al.*, (2021) found that through the integration of LDSF and with the development of soil spectroscope and health observation data, it is possible to estimate and map Soil Organic Carbon (SOC) concentrations with high precision, this allows to pinpoint regions for restoration and monitor interventions over time. Regardless of the effectiveness and all the advantages of LDSF in monitoring and evaluation of land degradation, in SSA, particularly in East Africa LDSF has not been effectively utilized.

Utilization of Geographical Information System (GIS) and Remote Sensing (RS)

GIS and RS are now reported as making important contributions to natural resource management, including land degradation and soil erosion rate determination (Chiemela *et al.*, 2018; Jiru, 2019). Due to the use of RS and GIS technologies, land degradation and its geographical distribution is now possible with reasonable costs and better accuracy across the greater parts of the regions (Reddy *et al.*, 2018). It has been shown that the utilization of space borne multispectral data can be used to learn more about the characteristics, scope, distribution, and extent of degradation (Hank *et al.*, 2019). Remote sensing-based assessments and monitoring of land degradation have several benefits, including consistent data, a source for spatially detailed data, and reporting that is nearly real-time (Reith *et al.*, 2021). When ground data is paired with high-resolution remote sensing data, digital elevation models made from satellite data like that from Cartosat-1 and Cartosat-2, and Light Detection and Ranging (LiDAR), there is a great deal of promise for evaluating land degradation at local scales (Gianinetto, 2008).

Through the integration of RS, GIS, and Revised Universal Soil Loss Equation (RUSLE), estimation of the amount of soil erosion loss on a cell-by-cell basis is achieved (Alexakis *et al.*, 2013). Lu *et al.*, (2004) showed that the use of geostatistical approaches to integrate ground dataset, thematic mapper (TM), and digital elevation model (DEM) data produces noticeably better results than using conventional methods to forecast soil erosion loss. RS data has been reportedly used as a potential tool for developing a cover management factor by using land cover classifications (Murambadoro, 2011), while GIS technologies might be utilized to integrate the RUSLE factors for the estimation of soil erosion (Kabanza *et al.*, 2013). GIS capability becomes more useful when used with empirical and predictive models in the assessment of soil loss. Ganasri & Ramesh (2016) and Kunta (2009) studied the uses of GIS in estimating soil erosion and concluded that GIS held enormous promise for enhancing soil erosion estimation compared to methods that did not use GIS.

Several remote sensing datasets have been used to measure and track soil erosion in sub-Saharan Africa, including satellite data with coarse, medium, and fine spatial and spectral resolutions as well as image-derived products like Digital Elevation Models (DEM) (Seutloali *et al.*, 2018). For instance Taruvinga *et al.*, (2008) in their study conducted in South Africa concluded that the Normalized Difference Vegetation Index (NVDI) and Transformed Soil Adjusted Vegetation Index (TSAVI) can successfully map continuous gullies with a moderate level of agreement when compared to traditional gully mapping method. Using slope classes and vegetation cover data produced from DEM and Landsat imagery, respectively, a study conducted in Tanzania by Vrieling *et al.*, (2006) reliably identifies soil erosion risk quickly and accurately across vast special regions. Moreover, the study conducted by Panagos *et al.*, (2014) in the European continent showed that the Moderate Resolution Imaging Spectroradiometer (MODIS) datasets, which are available for free, have the potential to be included in environmental models that deal with soil erosion. Additionally, they showed how MODIS-derived products enhance the spatial and temporal monitoring of biophysical features such as vegetation over vast geographic areas such as continents.

RS and GIS technology give timely results in land degradation research as was evident in mapping degraded land in space and time with its distinct advantages of systematic, synoptic, fast, and repeating coverage (Metternicht & Zinck, 2003). The use of GIS and RS technology in managing degraded soils has been significantly expanded worldwide due to its quick development and its capabilities with new tools and software. According to studies, RS and GIS applications together have a lot of potential for assessing, mapping and monitoring land degradation over a wider region with less expense and more accuracy than would be achievable alone. Incorporation of emerging techniques such as GIS and remote sensing in the planning, and implementation of conservation strategies has many potential benefits including the identification of areas that are susceptible to soil erosion caused by land use land cover change. These techniques help to identify where conservation efforts and priorities should be focused (Ghosh *et al.*, 2023). It can also be used to evaluate the extent of land degradation such as the rate of soil erosion, develop soil conservation strategies, estimate sediment yield, and design effective water management plans (Aouadj *et al.*, 2023). Moreover, GIS and Remote Sensing can map soil nutrient levels and projections of crop yield which help farmers to optimize the use of agricultural inputs such as fertilizers and other inputs more efficiently. However, in Sub-Saharan Africa, their utilization in managing and restoring degraded land is still minimal.

Techniques for Land Restoration in Sub-Saharan Africa

Restoration of degraded land is a tendency to bring abandoned or previously degraded land back into useful or productive use and enhance the expansion of the productive area without compromising natural ecosystems (Chabay, 2018). Restoration of degraded land requires different methods depending on the agent of degradation, severity, and the aim of restoration (Stanturf *et al*., 2014). Restoration of degraded agricultural land can be done to increase productivity, enhance ecosystem services, or restore saline soil. Restoration techniques can be grouped into two categories: (i) agricultural conservation techniques and (ii) soil amendment techniques.

Agricultural Conservation Techniques

Conservation agriculture

Conservation agriculture (CA) is a type of agricultural production system that is efficient in resources to ensure production intensification and crop yield improvement while enhancing natural resources through the improvement of soil nutrition and pest management. The main elements of CA for rainfed farming are reduced tillage, diversified crop rotation, soil cover, and soil moisture conservation, which when applied correctly result in enhanced soil health and contribute to crop yield sustainability (Shrestha *et al*., 2020). Tillage intensity reduction and residue retention are crucial CA components, but in small-scale farming systems in developing countries where crop leftovers can also be used as fodder and fuel wood, recycling or adding organic matter from outside sources may be an alternative. Many researchers have reported a positive contribution of CA on soil quality in Sub-Saharan Africa. The benefits of CA on soil quality vary from increasing productivity to improving soil organic carbon (SOC), infiltration, and soil moisture.

An increase in crop yield was the major benefit of CA reported, according to Thierfelder *et al*.,(2013) yield gains of 5 t/ha and 1 t/ha on maize and cowpea respectively were recorded after CA was applied in Zimbabwe and Zambia were recorded, taking into account that the average maize yield has been constant for the past two decades at roughly 0.89 t/ha. This milestone has been contributed by benefits contributed by different components of CA.

The application of mulching on CA covers the soil surface as a result it protects the soil from erosion. According to Mugandani & Mwadzingeni, (2021), CA reduces soil erosion and surface runoff by 90% and 67%, respectively. Apart from protection from surface erosion, soil cover will also regulate soil temperature, control weeds and increase organic matter in the soil after decomposing. According to research on the physical and biological features of soils in Zambia, directly seeded CA systems exhibited more stable soil aggregates (41%-45%) than the conventional method (24%) (Thierfelder *et al*., 2017). Because of these improvements in soil qualities and nutrient availability, CA has the potential to reduce external fertilizer inputs like fertilizers and pesticides, which over time may have negative consequences for the ecosystem and soil health. Apart from soil health, another potential benefit of CA practice such as reduced tillage and direct sowing is to reduce soil compaction which improves soil structure and nutrient uptake in degraded soils of SSA. In the areas with high soil erosion, CA may have the potential to plan and implement conservation and restoration efforts for degraded land in SSA due to its minimum soil disturbances which reduces the runoff and sediments yield. CA may also be potential in areas with low organic matter content due to its ability to increase soil organic matter through its practices of incorporation crop residues in the soil (Page *et al*., 2020).

Agroforestry

Agroforestry refers to the practice of purposely using woody perennials (trees, shrubs, palms, bamboo, etc.) on the same land management units as crops and/or animals, in some kind of spatial arrangement or temporal sequence. Various elements in agroforestry systems interact in a way that is both ecological and profitable. Another definition of agroforestry is a dynamic, ecology-based system for managing natural resources that, by incorporating trees into farms and agricultural landscapes, diversifies and sustains production for greater social, economic, and environmental advantages for all land users (FAO, 2015). The capacity of agroforestry to improve soil quality has long been considered a key advantage since it emerged as a scientifically accepted discipline and practice (Dollinger & Jose, 2018). For decades, both in the tropics and temperate areas of the world, agroforestry practices have been promoted for their proven advantages in enhancing not only soil quality but also other ecosystem services (Jose, 2009).

There are several agroforestry systems for recovering and enhancing soil health while simultaneously fulfilling the demands of poor resource farmers (Viswanath & Lubina, 2018). To counteract soil erosion and promote soil fertility, trees add nitrogen through nitrogen fixation, stabilize the soil, and be utilized in contour farming, and strip cropping. Trees planted in windbreaks and shelterbelts can help to prevent soil erosion (Misebo, 2018). To improve soil organic matter and nutritional status, Trees can be planted using enhanced fallow and alley cropping techniques, and the branches can be cut and used as mulch. However, by blocking the flow channel, an agroforestry system may also decrease runoff and reduce its ability to transfer soil (Kuyah *et al.*, 2019). Agroforestry can increase soil fertility, protect biodiversity, increase carbon sequestration, and help with climate change adaptation and mitigation.

According to Gupta, (2020) some agroforestry trees, including the *Leucaena, Acacia* and *Alnus* species, may fix up to 400-500 kg, 270 kg, and 100-300 kg of nitrogen per hectare per year, respectively. Furthermore, the annual major nutrients contributed by different agroforestry tree species range from 33.7 to 398 kg ha^{-1} $year^{-1}$ N, 2 to 19.3 kg ha^{-1} $year^{-1}$ P, 20 to211 kg ha^{-1} $year^{-1}$ K, 14 to 98 kg ha^{-1} $year^{-1}$ Ca and 5 to 17 kg ha^{-1} $year^{-1}$ Mg (Dagar *et al.*, 2020). For instance, agroforestry in Ethiopia boosted infiltration and decreased surface runoff by as much as 81% (Nyong & Martin, 2019). A review of African studies found that in around 60% of situations when the interaction between agroforestry and the environment was examined, trees enhanced the provision of ecosystem services (mainly at the field scale) (Rosenstock *et al.*, 2019). Agroforestry has been shown to increase crop yield. For instance, a Zambian study found that growing maize in an agroforestry system surrounded by covers of *Faidherbia albida* trees resulted in yield increases of 88-190%. Results also indicate that contour hedges have reduced runoff by nearly 70% and that soils are better preserved with tree hedges than in untreated terraces (ICRAF, 2010). Agroforestry has numerous potential benefits at once, including restoring ecosystems and preserving biodiversity while also supplying food and income, as compared with other restoration strategies. Agroforestry can be used in improving soil fertility of degraded land through the practice of green manuring where leaves and tree branches are left to decompose in the soil. This practice improves soil structure, soil aeration, and soil nutrient content. Agroforestry can be used for water conservation in soils with low water holding capacity,

Besides its multiple benefits its adoption is still low in SSA due to many reasons including high initial investment costs and delay or long-term return (Mwase *et al.*, 2015). To support sustainable land productivity, enhance biodiversity, and improve ecosystem services at the plot and landscape scales, effective agroforestry systems must be developed. This now calls for researchers to investigate the affordable and efficient agroforestry system for restoring SSA-degraded land.

Cover cropping

Cover crops (CCs) are any live ground cover that grows to protect the soil, seed, and enhance the soil between periods of normal crop growth or between trees in orchards and vines in vineyards (Fageria *et al.*, 2005). These plants are often known as "green manure crops." Cover cropping is the process of planting crops to cover the soil's surface to reduce wind and water erosion (Saturday, 2018). CCs can be any plants but mostly are legumes or non-legumes/grass. Crop production is increased by CCs through enhancing the physical, chemical, and biological characteristics of the soil. Many studies have reported the potential of cover crops on soil qualities (Coombs *et al.*, 2017). CCs regulate soil heat and temperature hence creating a favorable environment for the microorganisms.

When fallen leaves are decomposed, become sources of organic matter in the soil. CCs help to store moisture, reduce evaporation from the soil surface, reduce the kinetic energy of raindrops on the ground, and increase the amount of soil moisture (Sharma *et al.*, 2018). Additionally, CCs reduce soil erosion caused by wind and water, as well as particulate matter emissions brought on by wind and machinery.

According to Kaspar & Singer, (2015) soils planted with rye and oats as CCs showed a 54 and 89% decrease in rill erosion after 3 years (Kaspar & Singer, 2015). Other studies have found that CCs increase water infiltration by up to 629%, increase macropores by around 33%, and reduce soil bulk density by roughly 4% when compared to soil without CCs. According to reports, these changes could result in a 96% decrease in soil loss. (Haruna *et al.*, 2020). Wet aggregate stability, macroporosity, and water infiltration are all improved by an average of 16%, 16%, and 62%, respectively, by CCs, which also reduce penetration resistance (compaction indicator) by an average of 5% (Blanco-Canqui & Ruis, 2020). According to Brennan & Acosta-Martinez, (2017) research, the soil food web has improved as microbial biomass carbon has increased from 40 mg kg1 to 200-250 mg kg1. Other researchers reported an increase of SOC by 15.6 - 17.9g kg^{-1} (Adetunji *et al.*, 2020). Furthermore, perennial legumes, such as those used as legume cover crops, can produce up to 10 t ha^{-1} of dry matter and fix up to 120kg N ha^{-1} annually (Agegnehu & Amede, 2017). CCs are one of the important strategies for improving soil fertility in cropping land, but their impact on restoring degraded land when combined with other techniques such as physical structures is still not well documented. Therefore, much more research must be done to determine how CCs and physical structures work together to improve the health of degraded land in SSA.

Crop rotation

Crop rotation is a practice that involves growing a range of unrelated crops in the same place over multiple seasons to gain benefits such as reducing the spread of disease and pests that appear when one species is constantly cultivated (Rechcigl, 2018). By balancing the nutrient demands of various crops, crop rotation prevents the loss of soil nutrients. Crop rotation has a long-standing component of replacing nitrogen with the use of green manure and legumes planted after cereals and other crops. By alternating shallow- and deep-rooted crops, crop rotation can help improve soil fertility and structure.

A three-year study in Ethiopia on the interaction of crop rotation and manure application interventions improved the maximum average bulk density (BD), pH, cation exchange capacity (CEC), organic carbon (OC), total nitrogen (TN), available phosphorus (AP), and exchangeable potassium (EK) contents of the experimental soils, respectively, by 22.63%, 17.87%, 66.82%, and 88.89%, 150.00%, 88.87%, and 44.12%, compared to the baseline state of the soil's qualities before the experiment began (Alemayehu *et al.*, 2020). On the other hand, research done by Njaimwe, (2010) in South Africa reported yield increases of 13 and 29% for 2 years of soybeans-maize and 3 years of maize - dry bean - wheat rotations, respectively.

There are many potential benefits of incorporating crop rotation in soil conservation and restoration of degraded land in SSA these include improved soil fertility. Through crop rotation, specific demand for certain nutrients is rotated, hence reducing the possibility of depletion of specific nutrients in the soil. Not only that but also different crops take up different nutrients from the soil this is important for the soil to balance its nutrients for plant growth (Li *et al.*, 2023). Reduced soil erosion is another potential benefit of incorporating crop rotation in soil conservation and restoration. Through crop rotation, the soil is provided with year-round soil cover which reduces the likelihood of soil erosion. Crops have different root systems which helps them to hold the soil and reduce soil erosion through runoff. Moreover, crop rotation increases soil organic matter, and through increased soil organic matter, soil structure and nutrition of soil microorganisms will be improved which is important for soil health and nutrient cycling.

Organic Agriculture for Land Restoration

Organic agriculture is a method of farming that avoids the use of chemicals like synthetic fertilizers and pesticides, as well as genetically modified organisms (GMOs) and a variety of other synthetic food additives (Topwal *et al.*, 2018). The evolution of organic farming may be dated to the 1920s to 1930s in North Europe, primarily in Germany and the United Kingdom. It is now widely practiced around the world (Nielsen, 2019). Organic farming has evolved into a comprehensive strategy to combat contaminated food production, health security, biodiversity loss, interrupted soil nutrient cycles, polluted soil, and degraded agricultural land (Skoufogianni *et al.*, 2016). The use of organic inputs, which do not deplete soil nutrients, the encouragement of soil microbial growth, and the management of soil from texture to ecosystem are today's organic farming ethics (Lal, 2015). Organic farming relies on many farming systems that take full use of ecological cycles to protect soil fertility. The use of green manure cover crops, polyculture, intercropping, crop rotation, and mulching are all part of organic farming techniques that increase soil fertility (Kumar *et al.*, 2020).

Although soil properties are typically site-specific, several scholars have demonstrated that organic farming outperforms conventional farming in terms of both biophysical (such as SOM, stored nutrients) and biological (such as biodiversity) factors in maintaining or enhancing soil quality (Niemiec *et al.*, 2020; Zandi & Basu, 2016). It has also been suggested that combining organic and mineral fertilizers could be a viable strategy for addressing soil fertility reduction in SSA (Agegnehu & Amede, 2017). When a reference is made to Europe and the United States, a significant increase in SOM content as well as better biochemical performance indicators, there is no doubt that the adoption of organic farming would greatly reduce agricultural land degradation in SSA. Organic farming also dramatically reduces soil erosion by up to four times (Novara *et al.*, 2019). In organic farming, techniques to reduce N loss such as manure application and conservation agriculture and increase N absorption efficiency are frequently employed, and many investigations show that organic farming reduces N loss through leaching and enhances N uptake efficiency (Dahlin *et al.*, 2005; Farzadfar *et al.*, 2021). According to Bai *et al.*, (2018), The type and quantity of applied organic matter affect SOM's contribution to soil sustainability. Adding compost, farmyard manure, and slurry to the top 10 cm of soil raised SOM by 37%, 23%, and 21%, respectively. For every 1% increase in SOM concentration, estimations show that the soil may hold 10-11 liters of plant-available water per hectare of soil at a depth of 30 cm (Libohova *et al.*, 2018). Organic fertilizers are mostly made up of farmyard manure, green manure, and composts. For instance, Quinton & Tyrrel, (2006) reported that manure reduces surface runoff by 70-90% and soil loss by 80-95%. SSA being among regions with high livestock density Otte *et al.*, (2019) the option of manure application to restore degraded agricultural lands would be easily encouraged. Organic farming can result in soil erosion rates that are 30-140 percent lower as compared to conventional farming (Kumawat *et al.*, 2018).

Microbes easily colonize organic additions, which improves other soil qualities while maintaining fertility stability. To continually release nutrients for plant and microbial growth, a balanced ratio of microbial biomass and activity is required. Organic farming contributes to soil fertility stabilization by boosting nitrogen fixation, lowering nutrient leaching, improving SOM, and soil cover, and improving soil structure (Asoegwu *et al.*, 2020; Avasthe & Babu, 2017).

According to certain research, organic farming is typically associated with a significantly higher level of biological activity, which includes bacteria, fungi, springtails, mites, and earthworms (Purohit, 2020). Biodynamic and organic management significantly improved soil ecological performance in the long term. According to studies, microbial biomass and activity increase under organic farming leading to increased root length of crops of up to 40% compared to the ones under conventional farming systems. The biomass and number of earthworms were also 30% to 320% higher in organic farming than in conventional farming (Gomiero, 2013; Oehl *et al.*, 2004).

Transition to Perennial Crops for Land Restoration

Since the 1980s, several researchers have advocated for a shift from annual crop agriculture to perennial crop agriculture to avoid the negative effects of tillage and to eliminate or considerably reduce the use of agrochemicals (Gomiero, 2013; Molnar *et al.*, 2013). There seem to be several benefits to perennial crops: (i) Outperform typical annual crops in terms of ecological activities including carbon sequestration, nitrogen cycling, and water conservation by over 50%. They excel in preserving topsoil, reducing nitrogen losses by 30 - 50 times, and sequestering 300 - 1100 kg C/ha annually, aiding climate change mitigation, (ii) They need fewer runs of farm equipment, less pesticide and fertilizer inputs, and reduced management expenses because they don't need to be replanted every year. As a result, they consume less fossil fuel. (iii) The price of herbicides used in the production of annual crops is 4 - 8.5 times more than that used in the production of perennial crops, therefore the farmer will spend less money and have a far smaller impact on the environment by using fewer inputs in perennial systems. To increase yields and develop post-harvest processing methods that can use more perennial crops, further effort is still required. The majority of climate change models forecast temperature increases and perennial crops are likely better equipped to withstand these changes.

Perennial crops considerably boost the soil organic carbon (SOC) stored and the SOC content at 4% and 11%, respectively (Ledo *et al.*, 2020). Furthermore, Mcgowan *et al.* (2019) in Kansas USA found a significant increase of SOC stock from the perennial crops switchgrass by 0.8 Mg $ha^{-1}yr^{-1}$ and miscanthus by 1.3 Mg $ha^{-1}yr^{-1}$. Additionally, a five-year study conducted by German Emmerling *et al.*, (2017) revealed improvements in earthworm activity (cast production) on perennial crops compared to annual crops as well as increases in soil microbial biomass from 13-27% and average soil organic carbon contents of 1-2%. According to Fernando *et al.*, (2018), in a study on the environmental impact assessment of perennial crops on marginal soils, perennial crops have an average of 2.2 and 5.6 influence on soil characteristics and erodibility, respectively.

Soil Biotechnology for Restoring Degraded Cropland

Soil biotechnology is referred to as "the study and manipulation of soil microorganisms and their metabolic activities to maximize agricultural productivity" (Björnberg *et al.*, 2015; Weerasekara *et al.*, 2017). Soil biotechnology is a discipline of soil science that has become increasingly important in recent years due to its huge potential for enhancing plant nutrient availability, physical characteristics, xenobiotic chemical degradation, waste management, plant-beneficial symbiosis, and reduction of soil-born diseases (Mishra *et al.*, 2016; Singh & Gupta, 2016). The soil biotechnological method can be utilized in soil management practices by activating soil microorganisms to produce bio-fertilizers, and natural growth regulator chemicals, and improve organic matter and soil structure, especially in compacted soil management or non-tillage agriculture (Nath Yadav, 2017).

Biotechnology and agricultural techniques have evolved together to solve a variety of problems and enhance agricultural sustainability as awareness of agroecosystem functioning and optimum management practices has grown (Vanloqueren & Baret, 2009). Bacterial and fungal microbes are vital in soil restoration. For instance, extracellular polysaccharides released by cyanobacteria after they fix atmospheric nitrogen are broken down by soil microbes Singh & Gupta, 2016). These bacteria also create other bioactive compounds that benefit soil health and reduce soil pathogens as a result increase crop performance (A. Haruna & Yahaya, 2021). By supplying N, biological N_2-fixing bacteria support the growth and survival of other soil microbial communities in the rhizosphere (Igiehon, 2018). Most bacteria are known to release extracellular polysaccharides that facilitate soil aggregation (Sher *et al.*, 2020) and some mobilize soil P, K, and Fe that are fixed or inaccessible to plants and other microorganisms (Meena *et al.*, 2017). Furthermore, bacterial inoculae release phytohormones (Auxin/Indole Acetic Acid) that help plants grow and develop (Ahemad & Kibret, 2014). Ectomycorrhizal and Arbuscular Mycorrhizal Fungi (AMF) also improve soil fertility and water transport by exploring hyphal networks in the soil and producing organic acids that help to mobilize fixed nutrients (Otaiku *et al.*, 2022; Rashid *et al.*, 2016). According to research by Sadeghi *et al.*, (2017) conducted in Iran, compared to the control, the runoff coefficient was lowered by 96%, the peak was decreased by 83%, the commencement time was advanced by 168%, and the time to peak was decreased by 34%.

Through a process called translocation, AMF may transfer N, P, K, Fe, and other nutrients from the soil to the host plants (Rashid *et al.*, 2016). AM fungus can increase the amount of nutrients taken up by their roots and decrease the amount of nutrients lost by leaching, N_2O emission, and nutrient uptake (Bowles *et al.*, 2018; Qiu *et al.*, 2022). Microbial inocula control nutrient cycling and determine whether nutrients are available to plants as a result of these activities. These microbial inocula can restore deteriorated soil to acceptable levels by doing so. Seneviratne *et al.*, (2011) found that applying biofilm-based fertilizers made from N_2 fixer bacteria increased both the soil's organic carbon content and N_2 fixing. These fertilizers promoted ecosystem function and helped the tropics' deteriorated agricultural soil to be sustainably restored within a few months. The microbial communities observed in these biofilm-based fertilizers greatly improved microbial biodiversity, resulting in the sustainability of agroecosystems and the environment

Additionally, bacteria carried out various soil functions such as the stabilization, decomposition, mobilization, translocation, and mineralization of nutrients as well as the production and stability of aggregates. Due to the diverse microbial variety in these soil habitats, the above-mentioned potential of soil microbes has not been adequately utilized to achieve sustainable productivity in agroecosystems. As a result, it's critical to continue researching undiscovered microbes that can thrive in a competitive ecosystem in the field environment and help restore degraded soil health and production to meet rising global food demand while also ensuring environmental sustainability.

Soil Management Techniques

Application of manure and mineral fertilizers

Manure and fertilizer applications are crucial for restoring degraded agricultural land. They supply vital nutrients to the soil for crop growth and development (Zingore *et al.*, 2008). Fast-growing crops will cover the soil quickly and give more yield. Inorganic fertilizers supply plants with vital nutrients like nitrogen, phosphorus, potassium, and sulfur (Zaman *et al.*, 2009). Instead of using only inorganic fertilizers, it is better to apply both types of fertilizers together. The major sources of organic fertilizers are composts, green manure, and farmyard manure (Pinto *et al.*, 2017). Following the application of manure Zingore *et al.*, (2008) research in Mulerwa, Zimbabwe found that nitrogen levels rose by 40-60% and 17-38%, respectively, for Norfolk sandy soils and Cecil sandy loam soils. According to Smith *et al.*, (2007), the addition of manure in the soil reduces surface runoff by 70 to 90% and soil loss by 80 to 95%. A study done by Yamoah *et al.* (2002) in Ethiopia reported a high yield in millet grains and straw when crop wastes and fertilizers were used to restore degraded agricultural areas. Furthermore, Nalivata *et al.*, (2017) discovered that manure addition to the soil contributes nutrient concentrations ranging from 0.5 - 2.5% N, 0.4 - 3.9% P_2O_5, 1.2 - 8.4% K_2O, and 0.3 - 5.4% CaO. Legumes' green leaves contribute 2.9-4.4% N, 0.13-0.30% P, and 1-2.8 K in the soil.

The numerous advantages of manure for soil fertility in degraded land are still little recognized, despite prior research showing that applying dung and fertilizers boosts agricultural yields in SSA. The majority of research on manure and fertilizers in sub-

Saharan Africa has generally been on their role in providing crops with the N they need, with little focus on their capacity to enhance soil quality in degraded land (Zingore *et al.*, 2015).

Physical Soil and Water Conservation Measures

Physical structures are long-lasting features composed of dirt and stones that are used to restore agricultural land, prevent soil erosion, and uncontrolled runoff, and hold back water where it is needed (Bashir *et al.*, 2017). Cutoff drains and retention ditches are some examples of physical structures used to restore degraded land. Cutoff drains are constructed to properly capture surface runoff and transport it to an outlet, such as a canal or stream, cut-off drains are constructed across a slope. Their principal function is to divert water from gully heads and preserve cultivated land from uncontrolled flow (Tadesse & Belay, 2004). Retention ditches absorb and hold incoming runoff water until it sinks into the ground, retention ditches are built along contours. When there is no adjacent channel for the water to be discharged, they serve as an alternative to cut-off drains. Retention ditches are occasionally utilized for water gathering in semiarid regions (Enki *et al.*, 2001).

Physical soil and water conservation structures slow down runoff by an average of 13 - 71%. Level *Fanya juu* and *Fanya chini* terraces reduce runoff by 71% while tied ridges, bench terraces, trash lines, and stone buds reduce runoff by 51 - 57% (Wolka *et al.*, 2018). Their effectiveness differs from one location to another due to different factors such as soil types and rainfall. For example, in Tanzania, researchers reported that contour ditches lower surface runoff by 54-95% (Tenge *et al.*, 2011), while soil bunds were reported to lower the surface runoff by 17-94% in Ethiopia (Amare *et al.*, 2014). Apart from the reduction of surface runoff, physical soil conservation structures reduce soil loss. The average soil loss reduced by PSWC range from 39-83%. Tied ridges can reduce more than 60% of soil loss on average (Tenge *et al.*, 2011), compared to contour ditches (Fanya juu) which were reported to reduce up to 70% in Kenya, Tanzania, and Ethiopia (Gebrernichael *et al.*, 2005; Teshome *et al.*, 2013). These technologies must be tested in different environments before being adopted by farmers to improve their specific performance. Furthermore, research should be done to evaluate their effectiveness when combined with other soil conservation techniques like green manure cover crops and grass strips in sloping lands.

Incorporation of physical soil structures in planning and implementing conservation and restoration efforts for degraded land in SSA yields many potential benefits such as control of soil erosion in areas which severe erosion. Physical conservation measures such as terracing, contour plowing, and sediment basin prevent soil erosion by reducing the velocity of running water and enhancing infiltration which is important for crop performance (Saggau *et al.*, 2023; Tilahun & Desta, 2021). Techniques such as contour plowing and strip cropping help to retain and distribute nutrients more effectively and minimize nutrient loss through soil erosion and runoff (Dutter *et al.*, 2023).

Conclusion

This paper aimed to explore land recovery potentials and restoring strategies in the region specifically focusing on sustainable and innovative approaches to restore degraded land. The study found that SSA has a vast potential in restoring degraded land ranging from land degradation monitoring and evaluation, agricultural conservation techniques, soil biotechnology, and soil management techniques. The increasing land degradation problem in SSA is due to the ineffective utilization of soil conservation techniques. Effective utilization of land recovery potential and strategies in SSA for the aim of restoring degraded land in the region will play a large part in addressing the land degradation that resulted in food insecurity in the SSA. This is because the area has a wealth of agricultural potential, including both soil resources and human capital. When the following suggestions are put into practice will help greatly in overcoming the land degradation problem:

i) The creation of participatory policies that allow governments to work successfully with local farmers to manage the soil sustainably using soil restoration and conservation technologies.

ii) Making better and more effective use of the large informational resources from previously completed soil conservation and restoration-based projects to satisfy the interests of all parties involved in agricultural growth.

iii) More trial farms and systems run by researchers and farmers using soil restoration techniques are being established in various parts of the region.

iv) Continued funding of agricultural research to encourage the creation of technology that will restore degraded land and increase yields using sustainable land management practices.

v) There is a need for the agent action to transform existing conventional agriculture into agricultural practices that ensure sustainability.

vi) More research incorporates the existing techniques with the emerging techniques for the restoration and conservation of degraded land in Sub-Saharan Africa.

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