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Review

Sustainable Farming in Practice: Building Resilient and Profitable Smallholder Agricultural Systems in Sub-Saharan Africa

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Abstract: Sub-Saharan Africa is at crossroads. With a rapidly growing population of 1.2 billion and changing climates, the continent faces major development challenges, including food insecurity, climate change, resource degradation, poverty, gender inequality, and social exclusion. While there are multiple competing narratives promoted in the high-input, industrialised world to address climate change and the resilience of agricultural systems (e.g., regenerative agriculture, agroecology), there is an ongoing debate and genuine questions about the appropriateness of these approaches to small-scale farmers in SSA. African agricultural systems are unique, characterised by low productivity, nutrient mining, land degradation, hoe culture, and fragmented and diversified small farms. Though environmental pollution and over-dependence on fossil fuel-powered mechanisation are rarely topping the priority list, climate change is becoming a major concern. The top-down narratives from environment-concerned communities lack the tools to address the most pressing and immediate challenge of local communities in Sub-Saharan Africa, namely (i) intensification by increased crop productivity per unit of inputs, (ii) increased access to rural energy forcing farmers to use available biomass for cooking instead of soil regeneration; (iii) the intent of no use or reduced mineral fertilisers, in a system marred by nutrient mining over centuries; and (iv) failure to address recurrent drought through integrated soil water management interventions. To address these specific challenges, we present context-specific, outcome-oriented farming solutions as a viable and appropriate strategy called 'sustainable farming'. We argue that the nature-based narratives will remain to be important but will be better adopted if they respond to local demands and context-specific challenges of small-scale farmers. By means of three successful land restoration programmes in East Africa, we present eight outcomes that should be addressed to ensure sustainable farming of small holdings and reduce the risk of climate change. For these innovations to be adopted at scale, we proposed to put in place incentive mechanisms and functional last-mile delivery systems.

Keywords: sustainable farming; regeneration; agroecology; livelihoods; environment; climate; smallholder

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1. Introduction

Africa faces multiple development challenges, including food insecurity, resource degradation, poverty, gender inequality, and social exclusion, aggravated by yield stagnation and climate change. Smallholder production is estimated to account for 50–70% of global food production [1], and increasing food demand for the growing population was mostly coming from land expansion, with a 34% crop land increase in Africa between 2003 and 2019 [2]. The cultivated area increased from 170 million hectares in 1963 to 272 million hectares in 2015, mostly through the conversion of forest and grasslands [3]. Increased pressure on natural resources, lack of security of land tenure [4,5], and exploitive market dynamics blocked any serious prospects of agricultural transformation. The cost of land degradation, the highest in the world, is 7% of Sub-Saharan Africa's (SSA) GDP [6]. Most environmental degradation and 'depressive dynamics' could be associated with imbalances in the dominant patterns of ownership, access, settlements and utilisation of natural and productive resources and the political economy that enable them [5]. Moreover, the farming systems of Africa are diverse in terms of access to land, livelihood options, length of the growing period, resources base and intensification levels [7]. The potential to achieve food security and resilient systems is mainly dictated by access to productive agricultural resources and services, along with input and output markets [7]. Moreover, about 50% of the population is vulnerable to extreme events, particularly climate change, which is mainly manifested through drought and flood. Drought in SSA is characterised by less rain, shorter and unpredictable rainy seasons, and heat stress, all of these varying greatly between sub-regions, with the Sahel and southern Africa most affected [8]. IPCC [8] revealed that precipitation in most parts of Africa is either in decline or unpredictable, with predictions showing long-term reductions.

In the context of food insecurity, a changing climate, dwindling natural resources and increasing social and economic inequalities, concerns for more healthy food systems and the ecosystem services that support them have been gaining momentum, particularly as more scientific evidence becomes available [7,8]. These concerns could have been partly addressed by employing sustainable intensification [SI] principles, which are defined as a process or system where agricultural yields are increased without adverse environmental impacts and without the conversion of additional non-agricultural land [9]. SI has been widely adopted and become a central pillar in the approach used by high external input-oriented industrial systems of production, with specialization in few commodities, large-scale mechanization and economies of scale. On the other hand, there has been slow adoption of SI by smallholder farming systems of Africa, which is constrained by low capital investment, fragmented land holdings, limited use of agricultural inputs, low level of mechanisation and malfunctional markets.

With the increasing risk of climate change, there is growing public interest to move from conventional, high-input-driven farming to nature-based solutions, namely agroecology or regenerative agriculture. However, several sets of definitions exist in the scientific literature, depending on the institutional concerns and priorities, e.g., refs. [10–14]. The most preferred definition is by Wezel et al. [15,16], which defined agroecology as a set of agricultural practices aiming to produce significant amounts of food while valuing ecological processes and ecosystem services. The thirteen principles [13,14] include biodiversity, soil health, animal health, input reduction, recycling, connectivity, land and resource governance, participation, synergies, co-creation of knowledge, fairness, social values and economic diversification. Similarly, GIZ [17] defined agroecology as a context-specific approach that uses, preserves and improves biological and ecological processes in agricultural systems through the diversification and promotion of interactions and synergies. FAO [13] emphasised the need to move beyond the definitions and rather focus on the identification of salient elements that could guide development partners to facilitate the transition towards sustainable agriculture and food systems, which consider local context [18].

Besides agroecology, regenerative agriculture has also been widely promoted in the global north. While the definition of regenerative agriculture (RA) is evolving, and there is no agreed-upon definition to date [1,10,19], it is described as farming and grazing practices that reverse climate change by rebuilding soil organic matter, and restoring degraded soil biodiversity, resulting in both carbon drawdown and improving ecosystem services [20]. Most of the RA practices give emphasis on increasing soil carbon, with the premise that it will increase crop yields and mitigate climate change [20,21]. Thus, the core philosophy of RA is restoring soils through building biological systems (Cover crops, crop rotation, composting, manure, inoculation and other microbial activities) and enhancement of resource use efficiency without the use of mineral fertilisers and other external inputs [20], where excessive use of external inputs (e.g., fertilisers) became sources of environmental concerns and climate risks. RA is an approach increasingly also adopted by commercial, often large-scale farmers or external investors [10]. As global coalitions are being established, such as Regen 10, to expand the adoption of regenerative practices, it is not yet apparent what this approach entails and how it differs from past frameworks. Vague and diverse definitions and lack of regulation and protection of the term lead to a situation in which organisations set their own interpretation of regenerative agriculture, depending on particular interests [10].

This paper examines whether the call for farming concepts like agroecology, regenerative agriculture, or sustainable intensification would address the challenges of small-scale producers in Sub-Saharan Africa without being clear on desired outcomes. What does it cost to adopt and promote these best practices? What are the potential trade-offs in adopting these practices between food security and the environment? And what are the benefits between short-term priorities and long-term goals for small-scale farmers?

The move towards sustainable and nature-based solutions should have satisfied the most pressing and immediate challenge of local communities in sub-Saharan Africa, which could be summarized as (i) Enhancing crop productivity of small-scale farms and landscapes and assuring food security, (ii) Reducing environmental degradation and enhancing resilience, and (iii) Enhancing climate change adaptation and managing risks. Most importantly, our goal in agriculture, which is producing enough food for the growing population, will often limit our ability to fully mimic natural ecosystems [22]. It became essential to strive for the vision of building resilient, sustainable and responsive smallholder agricultural systems that benefit both the people and the environment. Hence, there are calls to re-examine the different approaches considering the broader environmental, food security and socio-economic challenges of Africa [10,18,19].

The specific objectives of this paper are:

(a) Review the various narratives (agroecology, regenerative agriculture, sustainable intensification) from the perspective of smallholder farmers;
(b) Based on case studies, identify key lessons, best practices and innovations with high potential to address the multiple livelihood objectives of small-scale farmers;
(c) Introduce outcome-oriented and context-specific principles and approaches that would concomitantly address the complex and emerging challenges of climate risks and food insecurity.

2. Methods and Approaches

This paper is structured into four interlinked sections. Section 1 presents the approaches and methods used to assess the different narratives, followed by case studies (Section 2). This is followed by a detailed review of key principles and outcomes (Section 3) extracted from the case studies. Capitalising on the experience of AGRA, we suggested how these complex resources, management practices and innovation could reach farmers at a scale (Section 4).

We have identified three case studies from within SSA, mainly Ethiopia and Rwanda (Figure 1), whereby integrated natural resource management principles and approaches were applied at a scale to rehabilitate degraded lands, restore ecosystem services and increase the productivity of crops. Landscape features and project impacts are presented below (Cases I, II and III). The case studies displayed innovations and experiences addressing the multiple objectives of farmers and co-benefits of productivity and climate change adaptation.

Eleven key outcomes (a suite of goals) emerging from these case studies, which would respond to the immediate food security and climate risk management priorities of smallholders, were exposed to subject matter specialists for prioritisation and ranking using questionnaires and monkey surveys through three consecutive webinars (13 July, 28 July, 24 August 2021), whereby participants debated and collated the global knowledge and assessed the relevance of these outcomes from the perspective of smallholder African farmers. We chose the top eight outcomes to assess the relevance of the different narratives/approaches (agroecology, regenerative agriculture and sustainable intensification) to the context of smallholders and their farming systems. We conducted a survey with 93 experts to rank the four different approaches against the eight different outcomes (3 being the highest and 1 being the lowest), which was used to generate Figure 2.

Moreover, we reviewed the available literature and consulted a team of experts to assess the potential contributions of these different narratives to concomitantly address food security, climate change adaptation and land restoration. We conducted a literature search through the Web of Science (apps.webofknowledge.com accessed on 20 September 2022), Google Scholar (scholar.google.com, accessed on 5 October 2022), Scopus (www.scopus.com, accessed on 5 October 2022), AGRIS (agris.fao.org, accessed on 8 October 2022) and ResearchGate (https://www.researchgate.net, accessed on 5 October 2022). We searched the literature published up to 2022, using 'regenerative agriculture', 'agroecology', 'sustainable intensification', and 'sustainable farming' as key terms. Although over 200 publications were retrieved, about 55 publications that provided theoretical approaches and empirical evidence on problems and management of climate, environment and food security were considered.

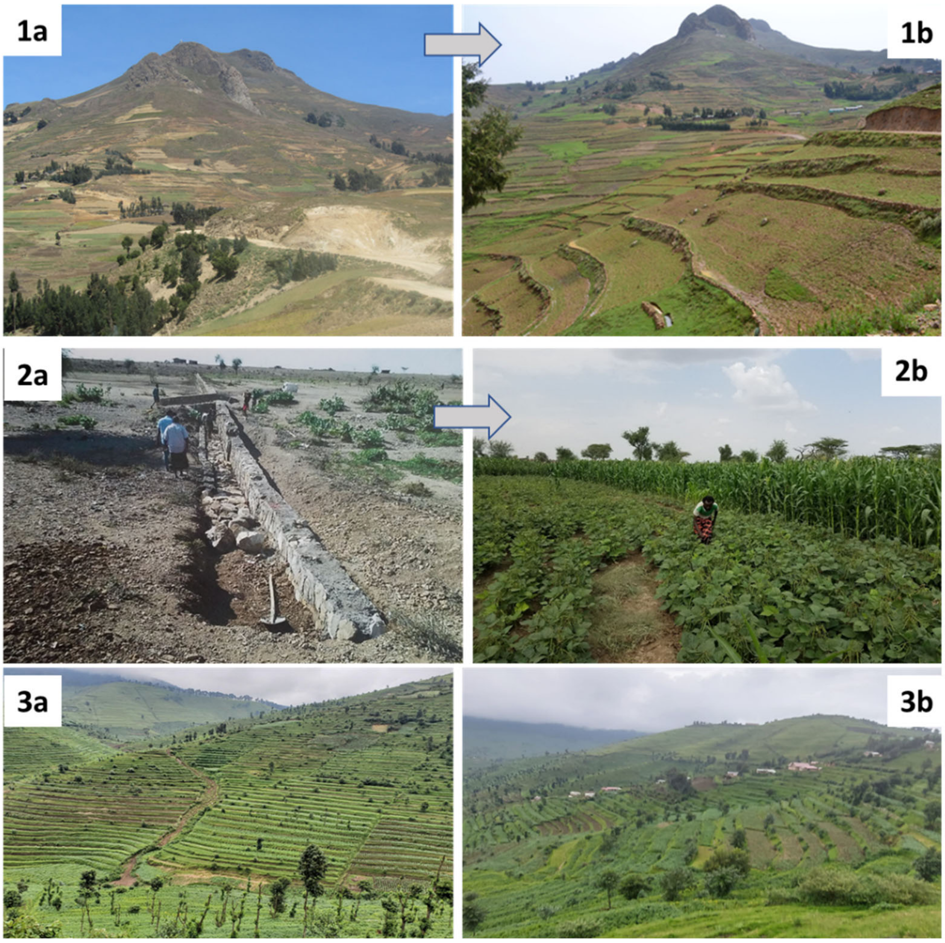

Figure 1. Rehabilitation of degraded landscapes and enhancing productivity of farms and production systems in Ethiopia (**1a**,**1b**,**2a**,**2b**) and Rwanda (**3a**,**3b**). The change from landscape 'a' to 'b' was achieved through collective action and targeted investments in land and water management.

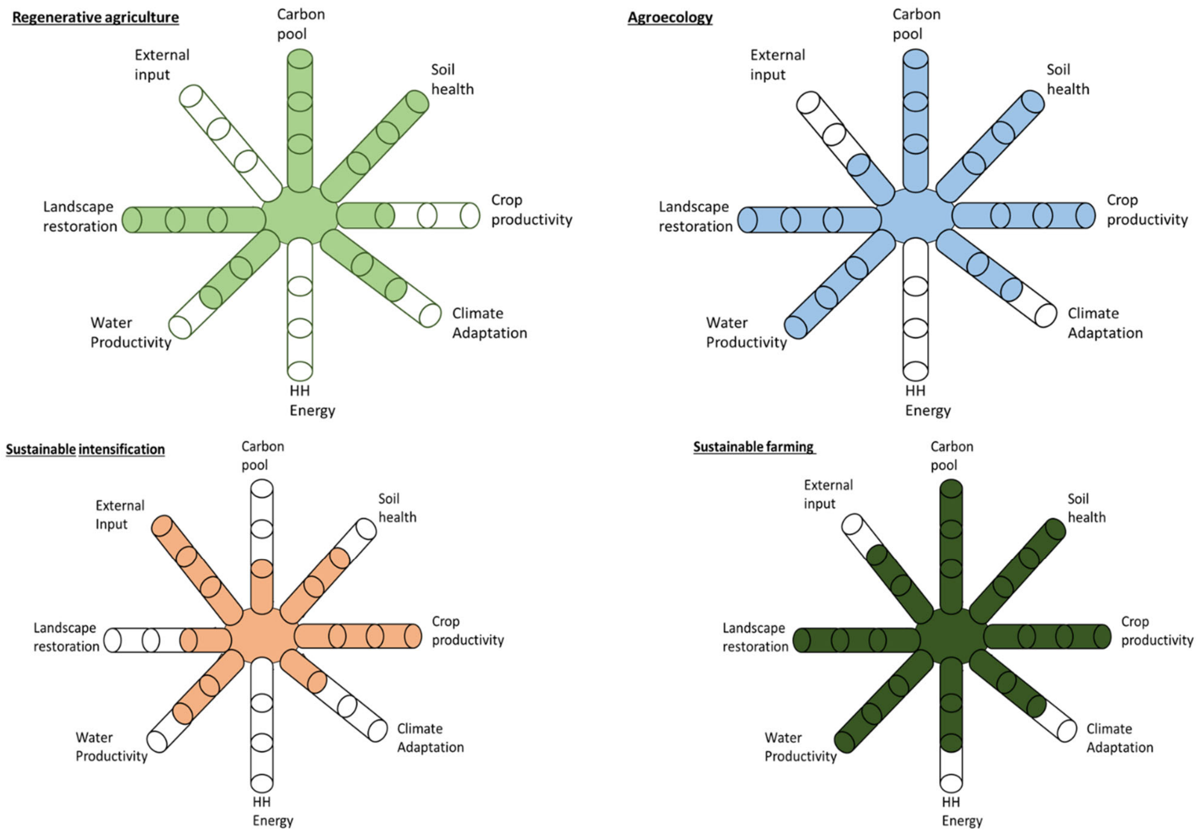

Figure 2. Characteristics of differing agricultural production systems and approaches that have been widely promoted and highlight the ultimate objects of these narratives and the methods used to achieve the intended goals. Each wing represents an outcome, with the colouring within the wing representing possible contributions to the stated outcome.

2.1. Case Study I: Restoring Degraded Landscapes for Rebuilding Livelihoods

Yewol watershed in the Amhara region of the Ethiopian highlands (Figure 1(1a,1b)) was a food-insecure, degraded landscape with strong upstream–downstream linkages [23]. Given its low soil fertility status, aggravated by soil erosion and soil acidity, the system was characterised by low productivity, few crop diversities and food deficit of local communities reaching up to five months in a year. Using participatory watershed management interventions and community mobilisation, it was possible to put 8000 ha of degraded land under soil and water conservation within three years. Researchers trained extension officers, introduced improved crop and forage varieties, cool season fruit trees (e.g., apple), and context-specific soil fertility management interventions such as green manuring during short rains and composting, facilitated collective action and enforcement of community by-laws to manage free riders. Researchers also trained district officers and development agents in seed multiplication of wheat and barley and quality control, soil and water conservation (SWC) techniques, market linkages, and community facilitation. The outcome of these investments was rewarding. Runoff and soil loss were reduced by an average of 27 and 37%, respectively, due to SWC practices at the plot level, while it reduced sediment yield at the watershed level by about 75% [24]. The amount of land downstream under irrigation increased from 270 ha to 940 ha of land in 6 years' time due to upstream recharge. Farmers were able to adapt improved crop varieties, while crop diversity in the landscape increased from 3 to 8. Farmers made composts and recycled nutrients for home garden use. Through the introduction of improved sheep breeds, the lambs were ready for market within three months, which became cash sources to buy critical farm inputs. Crop yield in wheat, barley and lentils increased by 60 to 100% starting from year 3, while the food shortage during peak seasons decreased by about 40% compared to non-target communities in adjacent watersheds. The project directly benefited about 40,000 people. This watershed attracted additional investment from district and zonal administrations, and the watershed became a learning site for the training of extension agents and officers for scaling and wider impact. It has even attracted the visit of top government officials of the country. Similarly, at a country level, a multi-donor-supported Sustainable Land Management Project in Ethiopia restored about 7.7 million ha of land and significantly enhanced farm productivity [25,26].

2.2. Case Study II: Managing Floods, Enriching Soils

In the agropastoral farming systems of Afar, in the Great Rift Valley of Ethiopia, communities have been affected by recurrent drought and torrential floods emerging from the neighbouring Amhara highlands [27]. Seasonal migration in search of water and pasture to neighbouring highlands for at least five months of the year is a common livelihood strategy. Besides, the abrupt floods used to destroy farms, rangelands and villages on a yearly basis. Moreover, there is severe competition for biomass between uses for livestock feed, soil fertility and cooking fuel. In this case study [27,28], a participatory flood management strategy was sought to increase water access to pastoralists by converting the horrendous flood emerging from the highlands to farms and rangelands for land rehabilitation using 'water spreading weirs' (WSW) as entry points. Cascaded weirs were built with an average distance of 75 m from each other to regulate seasonal floodwaters, redistribute excess flooding and silt and minimise erosion. The sediment-laden flood created differing land quality within the WSW-treated landscapes though the effect largely depended on the flood amount, composition and intensity. After dividing the landscape into different land qualities based on nutrient accumulation and soil water retention, about 47 ha of land was restored for growing crop and forage interventions. Crop and forage yield doubled compared to baseline within a season, while the flooded areas were producing up to 11.2 tonnes of crop residue per hectare against one-tonne neighbouring fields. The intervention changed the flow path and intensity of water spreading in the plain, which became an incentive for the communities to gradually settle; it also attracted additional investment from the local government in terms of the construction of elementary schools and a health post. Their local leaders were recognised by the local administration and were participating in critical decision-making. This innovation identified about 1.2 million ha of land suitable for flood-based land restoration within the Afar region [28], and the approach is being adopted as a key development intervention by the local government.

2.3. Case Study III: Hillside Irrigation for Commercialisation

Given its undulated landscape and associated extreme terrain variability, the Government of Rwanda recognised land degradation as a major threat to food security and the environment [29,30]. In response, in collaboration with major development partners like that of the World Bank (WB), it developed a flagship programme referred to as "Land Husbandry, Water Harvesting and Hillside Irrigation (LWH)", to reverse land degradation, increase agricultural productivity and facilitate commercialisation of hillside agriculture in multiple pilot watersheds covering about 30,250 hectares of land mainly in five regions [31,32]. The extensive investment in land and water conservation was designed not only to minimise erosion effects but also to develop hillside irrigation by draining and collecting excess rainwater from within the catchment [33]. The strong commitment of the government, along with the heavy engagement of the local community, led to the fast recovery of degraded landscapes within a period of five years and transformed several sites into major vegetable production areas, targeting the export market. The priority investment areas included capacity building of communities and local institutions in integrated landscape management, physical investments in designing and implementing soil conservation and water storage structures, implementing context-specific hillside supplementary irrigation, choice of appropriate crop and tree species fitting into the landscapes and soil types, integrated soil fertility management interventions including liming for managing soil acidity, and development and enforcement of by-laws and policies for sustainable management and use of rehabilitated landscapes [34]. They demarcated the landscapes into different Land Units based on slope, soil depth, soil fertility and erosivity index, which served as a guide for the implementation of the prescribed water and land management technologies and targeting of investments in the respective land uses [32]. For instance, in the Gishwati Water and Land Management (GWLM) Project site covering 6600 ha of land, about 45% of the entire landscape was allocated to natural forest regeneration, while the remaining was allotted for growing various food and tree crops and rangeland development. The outcome of LWH investment was that the marketed portion of the produce increased from 35% to 80%, farmers' incomes from sales increased by 130%, while access to finance by farmers increased by 85%. Close to 300,000 farmers benefited directly from these interventions [32], while the country attracted donor support as well as private investment to take it to scale. These experiences were taken to scale through the Bonn challenge covering about 700,000 ha of land and forest cover of 30% [35]. The opportunity for these investments in Rwanda is demonstrated by the existing heightened political will and commitment to supporting measures that constitute the national governance framework for forests, land and other aspects [35]. These projects have now evolved, and ownership has been slowly transferred to the local communities, though the initial role of the government in policy formulation and leadership and investment from development partners was critical.

3. Key Outcomes and Lessons from Case Studies

3.1. Need for Increasing Crop Yield and Productivity of Smallholder Farms

The current yield gap in smallholder farming remained very high, with actual rainfed maize yields ranging from 1.2 to 2.2 t ha^{-1}, which represents only 15–27% of the water-limited yield potential [36]. In smallholder subsistence settings, farm decisions are usually driven by short-term goals of increasing crop yield and reducing production costs of inputs and labour. The entry point to facilitate change in the Yewol watershed (Case I) was the introduction of context-specific crop varieties along with good agronomic practices fitting into the harsh and cold mountainous landscapes. The positive effects of rainwater management on crop yield were the major incentive for farmers to adopt land and water management practices, though the benefit was not visible until the third year. Land management practices, particularly mulching, tied-ridging, farmyard manure and compost, increased crop yield from 0.5 to 4 t ha^{-1} though the benefit varied with slopes and farmer management practices [37]. Land management practices increased yield not only by increasing nutrient availability and enhancing soil water holding capacity but also by reducing soil erosion that would have washed away seeds and nutrients and also by enhancing the soil–water holding capacity. The yield benefit in downstream farms was even more significant (Case II), with a more than 300% increase in maize yield due to upstream rainwater (flood) management and use as supplementary irrigation [27].

Enabling multi-functional landscape restoration. Countries should strive to sustainably support food security and the income of small-scale farmers in Africa without depleting the resource base for current and future generations. As demonstrated in the case studies (Cases I & III), the objectives of land restoration should not only prioritise environmental concerns, but also the livelihoods of small-scale farmers, including managing climate and market risks. The successes of the integrated landscape management projects (Cases I, II &III) combined the elements of traditional farmer knowledge with elements of modern ecological, economic, social and agronomic science, creating a dialogue from which the principles for designing and managing biodiverse and resilient farms are derived. For instance, investment in Rwanda (Case III) not only reduced soil erosion, but it also became a major vegetable-producing area using irrigation water, serving hillsides and downstream users.

The global community has been advocating for landscape restoration [20,35], whereby different resource flows between upstream and downstream communities are better coordinated (e.g., water), niche-specific innovations are promoted, and collective action is used to jointly manage communal resources while improving the management of farm and landscape-level resources. Investment in land restoration promotes regenerative agriculture and nature-based solutions (e.g., Cases II & III) and encourages the smart integration of technologies such as improved high-yielding seeds and critical/appropriate inputs, including mechanisation.

Given the Sustainable Development Goals (SDGs) challenges, there are increased calls for the diversification of farms and landscapes for enhanced resilience by growing complementary crops, varieties, forages, and trees and keeping animals to enhance biodiversity, improve land and water use efficiency, increase the diversity of food and nutrition, as well as reducing vulnerability to climate risks [38]. The decline in crop and tree diversification could be reversed by employing agroecological interventions, as was the case in Yewol (Case I). Increased above-ground diversity may also improve below-ground biodiversity, contributing to nutrient cycling and nitrogen fixation, the regulation of the dynamics of soil carbon sequestration and greenhouse gas emission, the effect on soil physical structure and water regimes, with a positive effect on plant health [14,39,40].

Judicious use of inputs. In SSA, the application of mineral fertilisers in farmers' fields has been extremely low. None of the countries use the minimum suggested rate of 50 kg of nutrient per hectare, a target set by the African Union at the Abuja Summit as far back as 2005. The average application rate of mineral fertiliser on arable land in Sub-Saharan Africa is 18 kg ha^{-1}, much lower than the 141, 154, 175 and 302 kg ha^{-1} in South Asia, the European Union, South America, and East Asia, respectively [41]. The use of mineral fertilisers in smallholder cropping systems is already limited in quantity (reduced input) due to limited access and market disincentives [18]. Moreover, African soils lack some critical nutrients, particularly phosphorus and micronutrients [42,43]. While farmers in Europe and the US could still produce a reasonably high yield with organic farming, mainly due to a significant build-up of nutrients in their soils due to decades of application of mineral fertilisers, African soils lack this pool of nutrients [19,42]. Given the fact that the available organic resources have very low P-content (<0.3 kg P/tonnes of dry crop residue) [44], it is also near impossible to solely satisfy the crop requirements with organic applications, and even worse in P-fixing soils. For instance, crop yield increment in the valley bottoms of Yewol (Case I) was possible mainly due to the targeted application of judicious use of critical nutrients. Given the largely low-input, low-output farming systems of SSA [7,9], it is crucial to promote loosely circular production systems, allowing the inward and outward flow of inputs, products, goods and services while ensuring the deliberate recycling of nutrients, water and other resources [40], including less hazardous chemicals, particularly when farmers encounter exotic and difficult pests and diseases that are hard to manage through conventional practices. For instance, investment in Biogas plants could have multiple benefits of producing high-quality fertilizers, reducing the risk of pests and disease but also reducing harmful emissions into the atmosphere. The introduction and use of inputs that are aligned with agroecological principles will be a key success factor in the agriculture and food system transformation journey in Africa.

The development of targeted fertiliser blends following soil maps and the facilitation of improved policy and regulatory systems could improve agronomic efficiency [44] and reach smallholder farmers with reduced costs and improved profitability. However, farmers' return from the use of external inputs is still limited [19,44]. We envision one game-changer in SSA being the rehabilitation of acid soils, particularly in high-potential, good rainfall areas. By creating public–private partnerships for increased availability and use of lime (e.g., Tanzania, Uganda, Rwanda, Ethiopia), it was possible to double production and productivity within a few years [44]. As also indicated above, the shortage of organic resources contributed to soil fertility decline significantly. For instance, a 3 tonnes/ha of maize grain yield would require at least 60 kg Nitrogen in good soils, which otherwise require about 6 tonnes of good quality organic manure to replenish, which is rarely available in these systems.

Regreening and increasing the carbon pool. There is severe competition for biomass between livestock feed, soil fertility, cooking fuel and other uses (Cases I & II), hence the need to increase biomass through regreening and judicious fertiliser application [19,45] to transform the existing farms and landscapes to sustainable farming.

The transition to climate-smart farming requires designing strategies for enhancing biomass production through farmer-focused innovations for regenerating and maintaining soil health and resilient landscapes. Regreening landscapes by increasing tree cover through enclosures, on-farm planting, agroforestry practices and community woodlots (Cases I & III) are critical for sequestering carbon while providing co-benefits in addressing food security and adaptation to climate change [46]. When land restoration potential is optimised, it creates an opportunity to tackle rising CO_2 levels that is both globally significant and economically attractive [46].

In almost every country in SSA, there are a few successful bright spots where communities have undergone substantial livelihood changes by intensively managing small patches of land within the farm for growing market-oriented products (e.g., fruits/home gardens) and restoring ecosystem functions [47]. They are commonly small plots around the house, valley bottoms and watering sources (Case I) that mimic an agroforest ecology in ecological function and structure. Such niches could be used as entry points to facilitate wider landscape movement. Moreover, reports from the region showed the potential role of market gardens as business-oriented farming and as an incentive for communities to invest in managing and restoring the edaphic and hydrological functions of landscapes [47]. They not only serve as income sources for women, but these patches of land are also used for multiplying high-value planting materials (e.g., grafted fruits), producing forage for fattening small ruminants and serving as bee forage for collective honey production [48]. It also serves as a pool for carbon sequestration and climate change adaptation. Given the limited amount of biomass required, the higher returns per unit of labour and water investments, improved household nutrition, and low risk in terms of theft and land tenure, home gardens could be promoted as a carbon sink in the wider cereal-based landscapes and systems.

Enhancing Soil Health: Extensive reviews in SSA showed that food security could not be achieved without improved management of African soils [42,44]. Investments in integrated soil fertility management (ISFM) [42,43], watershed management and other natural pathways [5,26] improve soil health, saves water, enhance above and below-ground biodiversity, increase the vegetative cover and reduce greenhouse gas emissions [17,40]. ISFM would increase crop productivity, reduce pressure on forests, help avoid land use changes by increasing the productivity of available arable land and help regenerate degraded lands by nutrient replacement and increasing the carbon pool. Targeted fertilisers, when used efficiently, also help to build carbon sinks in agricultural soils by maximising their biomass production, which results in higher levels of soil organic matter and soil organic carbon pool [45]. These benefits are also recognised in the FAO International Code of Conduct for the Sustainable Use and Management of Fertiliser [31].

In practice, nature-friendly intervention for improving soil health is not a new concept in Africa, and it has been implemented in many parts of the continent for centuries [18,48], with most examples emerging from land restoration (Cases I, II and III) and home garden development [47] in the sub-humid and humid parts of Africa (e.g., the Banana-Coffee based systems of Uganda, and Coffee-Enset based systems of the Ethiopian highlands). However, even though farmers are keen to fully adopt organic fertilisers, they rarely have enough manure and organic biomass to fertilise beyond 15-20% of their farms. The other drawback is the bulkiness and labour required to apply it. In these systems, the loss of grazing land with the expansion of cultivated areas and the associated decline in cattle manure are putting pressure on soil fertility and soil health [44].

Conserving and efficient use of water resources. Rainwater management constitutes mapping, storing and efficiently utilising rainwater to decrease unproductive water losses (runoff, evaporation, conveyance losses, deep percolation) from a system, as well as increasing the water use efficiency and profitability of farm enterprises [49]. Unlike conventional approaches, it focuses more on the institutions and policies rather than on the technologies (Case II) and advocates for improved water productivity in the soils, farms, landscapes, reservoirs and other facilities. Adopting small-scale irrigation using alternative water sources (Case III) would enhance the profitability of critical inputs of seeds and fertilizers in the era of unpredictable weather. The rainwater interventions would capitalise on local innovations like that of '*Zai*' [49], the low earthen dams called "*malambo*" in the Dodoma, Shinyanga and Pwani regions of Tanzania [50], and the Sustainable Land Management Practices of Ethiopia [25,26,37]. Moreover, integrated water management promotes the recycling and reuse of wastewater, saving irrigation water by choosing water-efficient crops and improving the performance of irrigation schemes and major basins. Upstream landscape management would also enable downstream irrigation through runoff harvesting and recycling systems (Case III).

Promote climate-resilient seeds and services: In SSA, farmers are exposed to extreme climate events, particularly recurrent drought and flooding (Case II, [8]). Farmers in drought-prone regions of SSA rarely adopt high-yielding, input-responsive crop varieties or fertiliser inputs due to the high risk of crop failure caused by drought. They may experience one or a combination of the following three different drought occurrences (Case II), namely (i) *Full season drought*: when the amount of rainfall is much lower than in normal years across the phenological stages, and hence crops did not get enough water to cover the atmospheric demand throughout the growing period. (ii) *Terminal drought*: when there is enough water for early establishment and growth, but later phenological stages are exposed to soil water deficit, and (iii) *Intermittent drought*: when there is an unpredictable short dry spell within a growing season and crops are exposed to drought at some stage of growth, especially at flowering. Climate-resilient sorghum and millet varieties, along with flood irrigation, helped farmers to produce up to two tonnes of grain per ha under drought conditions (Case II).

Moreover, farmers and agropastoralists in SSA have limited access to climate information services or the appropriate technologies and practices to respond to climate change. Agropastoralists in Afar (Case II) rarely receive an early warning system or advisory to minimise climate risks. They would benefit from context-specific climate information and prediction tools to make climate-smart decisions to mitigate drought, flood and other extreme events. It calls for capacity building of local-level climate service providers to produce timely and appropriate advisory services that would facilitate farmer and community decisions, reducing risks and enhancing the resilience of these fragile systems. Context-specific, high quality localized and timely weather information can then be paired with the latest climate-smart crops and agronomic practices so that farmers receive actionable, trustworthy information at the right time for their specific location. Moreover, there has been a wide variety of climate change adaptation mechanisms to minimise the negative effects of climate-change-induced drought effects [8,14], although these adaptation mechanisms are commonly community-specific and did not expand beyond specific localities.

Increasing access to alternative household energy. More than 90% of households in SSA rely on firewood and charcoal as primary sources of domestic energy [51]. They have also estimated that, on average, a household would use about 5 kg of firewood per day sourcing from forests, farm trees, crop residue and purchases. The limited electrification of rural households (e.g., Case I & II) has affected the farming systems in at least three different ways. (i) given the limited access to connect with major grids, farmers have been using crop residues, manure and other resources for cooking and warming houses at the expense of soil fertility and other uses; (ii) increased demand for household energy is a major factor of deforestation, affecting landscape health and climate change adaptation and (iii) lack of energy for mechanisation limits productivity by increasing labour cost, reducing farm productivity and causing post-harvest losses due to delay of operations, all of which would have affected local food systems. For instance, access to solar panels could be instrumental in running small-scale irrigation pumps, cooking stoves and household energy. Although access to solar panels is limited in SSA, Agrophotovoltaics, which is a strategy of saving prime agricultural land by using the same land area for generating both solar energy and agricultural products so that solar panels coexist with crops on the same surface, has been effectively used in India and other regions. Increased access to fodder would enable farmers to increase livestock ownership and provides an opportunity for the introduction of appropriate and affordable biogas technology (Case III). Implementation of small-scale biogas plants to produce valuable biogas that could be used for household cooking while at the same time producing high-quality fertilisers and reducing harmful emissions into the atmosphere could be an important intervention. One kg of cow dung can produce 0.036 m^3 of biogas [52]. Sustainable farming would not be achieved without increased investment in improving access to alternative household energy sources.

3.2. Would the Existing Approaches Lead to Major Outcomes?

The multiple and competing approaches have been promoted in the global north, namely agroecology, regenerative agriculture and sustainable intensification (Figure 2), though there is an ongoing debate about whether these narratives satisfy the multiple needs of African farmers [18,19]. Regenerative agriculture, agroecology, sustainable intensification, organic agriculture, etc., can all be seen as means to achieve a similar yet vaguely defined goal, namely sustainable agriculture [10].

Although Agroecology is considered a dynamic concept that has gained prominence in scientific discourse [16], it lacks the context of smallholder farmers in the global south [18]. For instance, nutrient recycling for soil health is interrupted by a lack of energy as most of the household biomass is used for cooking, which calls for rural energy to be a major component of agroecology. In SSA countries where fertiliser application is very low (<20 kg ha^{-1}), smallholder farms consider the use of fertilisers as a strategy for determining agricultural income [18]. As indicated in Figure 2, agroecology principles are prioritising soil health, soil carbon, landscape restoration and climate change adaptation, while productivity, high yield gap and use of external inputs are not necessarily top priorities. On the other hand, SSA is characterised by low-input agriculture that leads to low yields. To offset the yield gap, the region depends on further land clearing and deforestation [2], which has led to the rapid degradation of over 95 million hectares of land in SSA [6]. From the context of small-scale farmers in Africa, while 12 out of the 13 agroecological principles [16] are fundamental for providing a transition towards more sustainable food systems, the principle on input reduction did not realise the realities and circumstances of Africa, where farming is marred by nutrient mining and extremely low application of external inputs. Current use of external inputs is very low or non-existent, with about 18 kg ha^{-1} fertiliser compared to an average of 250 kg ha^{-1} in the global north [41]. Low-input use has only led to further land degradation and unsustainable farming [3,7,53]. Unlike in the global north, where chemical fertilisers became sources of environmental concerns, judicious and increased use of fertilisers in SSA would protect forests, wetlands and protected areas from encroachment in search for fertile land [10].

Similarly, as presented in Figure 2, regenerative agriculture is profoundly geared towards addressing environmental concerns of high-input agricultural systems [10,18,19] while it provides limited emphasis on enhancing crop yields, and improving productivity, rarely addressing food security concerns of smallholder farmers. With the current low crop yield per ha (with average maize yield below 2 t ha^{-1}), and lack of nutrient-rich biomass in the farming systems, increasing yield without external inputs is almost impossible [1,42]. In a system where food insecurity is a major concern, enhancing crop yield and productivity are more pressing needs of communities over long-term environmental issues [18]. While for some organisations, regenerative farming is unequivocally a form of organic agriculture, others are open to the judicious use of agrochemicals [19]. The key question is what the incentives for smallholder farmers are to employ regenerative practices for building soil health and landscape restoration. In other words, would smallholder farmers be able to prioritize long-term environmental benefits over immediate food security and income concerns? While acknowledging the long-term benefits of RA, who is paying for the transition is rarely addressed.

3.3. Merging Best-Bet Approaches Fitting to the African Context: Sustainable Farming?

As discussed above, the existing global narratives are missing out on major outcomes that affect the livelihoods of smallholder farmers, namely (i) crop productivity and associated food security, (ii) lack of rural energy forcing farmers to use available resources for cooking instead of soil regeneration; (iii) the intent of no use or reduced mineral fertilisers, instead of encouraging smallholder to use the judicious amount to address nutrient mining over centuries; (iv) and failure to address recurrent drought through irrigation and development of alternative water sources.

Capitalizing on lessons learned from the case studies and given the limited focus of regenerative agriculture and agroecology principles and practices to productivity and smallholder livelihoods (Figure 2), we propose an outcome-oriented framework for the transformation of African farmers' livelihoods and environmental services by filtering and combining the existing competing narratives to better serve small-scale producers' interests, called '*Sustainable farming*'. Sustainable farming capitalises on ecological concepts and principles that optimize interactions between plants, animals, humans and the environment, taking into consideration the social aspects that need to be addressed for a sustainable and fair food system [10,13,16] and following a multi-pronged approach that simultaneously applies ecological principles, social and economic concepts to the design and management of fragile smallholder farming systems. It is driven by the local food systems, economic profitability, efficient and recycled use of renewable resources, benefiting from renewable energy, and, most importantly, adopting agroecological principles.

Sustainable farming (SF) is not necessarily centred on natural resources; rather, it is about the smallholder farmers, their aspirations, needs, livelihoods, rights, and how these needs interact with the resource base in a sustainable way. In addition to the established principles, it encompasses household energy, efficient use of mineral fertilisers and water management innovations. It also recognises that profitable farming and the ecosystem services they rely on are interrelated with one another within a defined agroecological system and, therefore, must be managed in an integrated manner [39]. Sustainable farming could facilitate behavioural change through two different incentive mechanisms, namely: the potential to maximise profit from producing more per unit of input and the potential to minimise risk from climatic and market shocks.

3.4. Implications of SF Interventions on Future Climate Change Adaptation

Climate change due to alterations in rainfall amount, onset and variability and temperature is most likely to increase the frequency of climate-induced hazards such as heat, droughts and floods in many parts of SSA [8]. Context-specific sustainable farming technologies and practices that would minimise the risks of climate change and enhance the resilience of systems need to be adopted by farmers and communities at large. Our detailed analysis using Global Climate Models [54] showed that Ethiopian highlands, which currently receive relatively high rainfall and are the major crop-producing areas dominated by maize, wheat and teff, will experience increased rainfall variability, by about 19%, under the future climate compared to the baseline. And yet, these areas will be less affected by climate change compared to the dry, fragile lowlands in the eastern and southern parts of the country. This could be explained by the huge investment in sustainable land management in these systems for the last 30 years (Case I, [25,26]), which has reduced soil erosion, increased vegetative cover and enhanced water recharge across these landscapes [25,26]. Interestingly, those dry areas where there is limited investment in land restoration, with less crop diversification and limited investment in irrigation (Case II), will also be the most sensitive to climate change events by 2050. Similarly, in Rwanda, the northern maize-dominated system will be more exposed to climate change in the future compared to the southern highlands [54]. However, those southern highland systems, currently less exposed to climate change, would be more sensitive to extreme events compared to the northern part of the country. This could be again explained by limited investment in soil and water conservation and land rehabilitation in the south, compared to areas that received government attention in the last decades (Case III).

4. Delivery of Sustainable Farming Technologies and Practices

Last-Mile Delivery of Interventions

In the continent where the public extension system has largely collapsed, and the farmer-to-extension ratio remains very high (1:3000), strengthening the private sector-led extension approach and the input distribution systems would be instrumental, along with context-specific extension content and a wider network of actors.

The extension capacity in SSA is very low, with a large extensionist-to-farmer ratio [55]. One of the most effective extension strategies is a private sector-led extension service by employing a self-employed village-based advisory (VBA) (https://agra.org/extension-capacity-building/ accessed on 10 November 2022), which has been developing over the years at AGRA [55]. Another model is the Farmer Service centres (https://ftma.org/kenya/ accessed on November 2022), which facilitate private extension services using a network of farmer centres. These private sector-driven models have the potential to reach a significant scale though the outcomes may not be realised until several years [56]. VBAs could reach many farmers, including women, at low cost, has good linkages with local government and private sector partners, had practical training in providing multiple last-mile delivery of inputs, markets and services required by farmers. One VBA is trained to teach sustainable farming methods, reaching up to 300 farmers. Localised content could be digitised to ensure it reaches all stakeholders at scale and connected to real-time weather and climate services for a data-driven approach to providing timely and relevant content. The model rapidly catalysed the adoption of inputs by farmers and resulted in increased land and labour productivity, making agriculture attractive for farmers, including the youth [55]. However, the sustainability of these models is still a challenge as the market and income incentives to sustain the private sector-led extensions are not yet well developed.

Context-specific, landscape-based farming interventions. The African continent is very diverse, comprising at least 16 distinct farming systems, with a mosaic of natural resources, climate, institutions, markets and agricultural services [7]. There is a need to promote context-specific farming technologies and practices that provide immediate benefits to farmers while contributing to long-term agroecological and sustainability goals. Farming interventions tailored to local resources will generally increase resource use efficiency and labour productivity and thereby reduce poverty. For instance, the dryland systems of the Sahel may use water-saving technologies as an entry point to enhance production, while the vertic soil-based Ethiopian highlands may need to drain the water from farms to maximise productivity while storing the extra water for alternative uses.

Promoting collective and Inclusive resources management. Enhancing food security and environmental health in SSA could not be achieved without the deliberate engagement of local communities and other stakeholders [5]. Intrahousehold gender relations would not only affect production and commodity choices but also the engagement with markets and intensification processes. A broader understanding of women's engagement in the value chain for a wide diversity of agricultural products would enhance technology adoption but also address the environmental concerns of the society at large. Moreover, landscape restoration and rehabilitation could not be done by individual farmers but rather calls for collective action (e.g., Cases I, II & III), joint investment and upstream–downstream relationships in sustainably managing common resources (e.g., irrigation water, rangelands). This also calls for a broader, inter-institutional partnership at landscape and ecosystem scales.

5. Conclusions and Further Research Needs

With changing climate, increasing food demand and dwindling natural resources, the risk of farming system collapse is very high, with the increasing impact of climate change and low response capacity, unless major changes are employed to change the course. Moreover, the nature-based approaches should respond to the immediate and long-term livelihood needs of smallholder farmers. Outcome-based approaches to sustainable farming would allow flexibility in terms of the processes that lead to those desired outcomes, particularly from the perspective of smallholders and their possible co-benefits. Small-scale agriculture would be best served by designing context-specific interventions and solution sets that take a systems approach and address several challenges simultaneously [38]. It also calls for participatory and integrated approaches linking farms with landscapes, produces with market opportunities, farmers with communities and appreciating upstream–downstream relationships.

The paper has limitations in that we did not present quantitative data to compare the different approaches under similar socio-economic situations; hence comparisons in terms of real benefits, profitability, food security and climate change adaptation are yet to be made. We identified two major knowledge gaps for further research to operationalise sustainable farming, namely (i) quantifying the stated outcomes under various socio-economic scenarios, farming systems and management options and (ii) establishing trade-offs and relationships among the different outcomes over time and space. The application of these narratives would require strong incentive mechanisms and the capacity to implement them across scales.

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