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Regenerative Agriculture as Pathways for Sustainable Food Systems Transformation in Low-Income Countries: Insights from Global Experiences (A Review)

Tekeba E*, Hiwote T, Konjit N, Mesele K, Dereje B, Alemayehu Z, Beza S, Befekadu K, Solomon A and Gizachew Z

SNV, Netherlands Development Organization, Addis Ababa, Ethiopia.

***Correspondence:**
Tekeba E, SNV, Netherlands Development Organization, Addis Ababa, Ethiopia.

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ABSTRACT

Current global evidence underscores the need for profound transformations in food production and consumption systems to sustainably feed a projected population of 10 billion by 2050. Such transformations are also essential to halt and reverse ecosystem degradation, protect biodiversity, conserve freshwater and soil resources, and limit global warming to below 1.5°C. At the same time, nearly one-third of global soils are moderately to severely degraded due to intensive agricultural practices. In the European Union alone, soil degradation is estimated to cost €97 billion annually, with a substantial share linked to human health impacts. Agriculture is also a major driver of biodiversity loss, threatening approximately 62% of globally at-risk species, largely due to land-use change and the widespread use of chemical pesticides. Although around 35% of global crop production depends on pollinators, more than 40% of insect species are in decline, with one-third facing potential extinction. Fertilizer application is also a major source of Nitrous Oxide (N_2O), a greenhouse gas nearly 300 times more potent than CO_2, with an atmospheric lifetime exceeding a century. Beyond environmental impacts, the agricultural sector is closely linked to persistent social and health challenges driven by inequalities within the global food system. More than 500 million farmers and fishers live in poverty, while nearly 800 million people experience hunger and approximately 2 billion are overweight or obese. Agriculture is the largest consumer of freshwater, accounting for about 70% of global withdrawals. The agri-food sector contributes roughly one-third of global greenhouse gas emissions, driven by unsustainable crop and livestock production, land-use change, deforestation, and food loss and waste. The accumulation of Methane (CH_4), Nitrous Oxide (N_2O), and Carbon Dioxide (CO_2) continues to intensify global warming. Climate change is already affecting agricultural productivity, with projections indicating significant yield declines, including up to 22% reductions in maize yields in parts of Europe and as much as 49% reductions in wheat yields in Southern Europe. Achieving the 1.5°C climate target will require halting further land-use change and restoring hundreds of millions of hectares of degraded ecosystems by 2050. In this context, this review aims to synthesize global evidence, foster collaboration and knowledge exchange, and draw on both successes and failures to inform the adaptation of regenerative agriculture practices in developing countries. These challenges highlight the urgent need to transition toward a more sustainable and equitable agri-food system—one that minimizes environmental impacts while enhancing resilience and securing livelihoods for farmers. Regenerative Agriculture (RA) offers a promising pathway by restoring ecosystems, improving soil health, enhancing productivity, and strengthening climate resilience through a set of guiding principles and practices. However, there is no single solution; scaling RA requires a combination of complementary strategies implemented in context-specific ways. Studies from the Rodale Institute, drawing on experiences from across 57 low-income countries, report average yield increases of 79%, with gains of up to 116% in African contexts. These practices have also improved water-use efficiency and reduced pesticide use by up to 71%, alongside yield increases of around 42% in many cases. Additional research across 20 African countries indicates that integrating composted manure with crop rotations can sequester up to 2,000 pounds of carbon per acre annually, compared to annual losses of nearly 300 pounds per acre in conventionally tilled systems reliant on synthetic fertilizers. Similarly, findings from long-

term farming systems trials show that regenerative systems can increase yields by up to 40% under drought conditions, generate 3–6 times higher profits, reduce energy use by approximately 45%, and lower carbon emissions by up to 40%, while minimizing harmful chemical runoff. Therefore, to bring holistic agri-food system transformation, we need to mainstream RA in the existing farming system at land scape rather than farm level, apply RA practices in aggregate instead of fragmentation, and application of Productive Use of Renewable Energy as an enabler, redirect subsidies and incentives toward soil restoration, carbon storage, composting, and agroforestry. Despite these demonstrated benefits and recommendations, transitioning to regenerative agriculture still requires time, patience, access to finance, inclusion, sustainable energy, enabling policy frameworks, strong stakeholder collaboration, increased awareness across value chain actors, more robust and long-term evidence generation to effectively measure and track outcomes.

Keywords
Biodiversity loss, Climate Change, Regenerative Agriculture, Pathways, Soil Health, System transformation.

Definitions

Definitions of terms	Reference
Regenerative Agriculture: is a holistic land management practice that leverages the power of photosynthesis in plants to close the carbon cycle and build soil health, crop resilience, biodiversity and nutrient density.	[1, 2]
Organic Agriculture: Organic agriculture is an integrated production management system that promotes and enhances agroecosystem health, including biodiversity, biological cycles and soil biological activity. It emphasizes the use of natural inputs (i.e. mineral and products derived from plants) and the renunciation of synthetic fertilizers, pesticides, and genetically modified seeds.	[3]
Conventional Agriculture: refers to a modern farming approach that heavily relies on synthetic chemical fertilizers, pesticides, and herbicides, as well as mechanization and monoculture practices. This method aims to maximize crop yields and efficiency but often leads to environmental concerns, such as soil degradation and biodiversity loss.	[4]
Climate-Smart Agriculture (CSA): is an integrated approach for managing landscapes, croplands, livestock, forests, and fisheries that address the interlinked challenges of food security and climate change. CSA is a set of agricultural practices and technologies which simultaneously boost productivity, enhance resilience and reduce GHG emissions. First, it has an explicit focus on addressing climate change in the agrifood system. Second, CSA systematically considers the synergies and trade-offs among productivity, adaptation, and mitigation.	[5]
Conservation Agriculture: Conservation agriculture (CA) is defined as an approach to managing agroecosystems that aims to improve and sustain productivity, increase profits, and enhance food security while preserving the resource base and the environment. It is characterized by three linked principles: continuous minimum mechanical soil disturbance, preservation of residues for permanent soil cover, and diversification of crop rotations.	[6, 7]
Subsistence Agriculture: Subsistence agriculture is defined as a farming method primarily used by small farmers that focuses on producing enough food to meet the needs of their families, typically without the use of modern equipment or chemical inputs.	[8]
Biodiversity conservation refers to the protection, upliftment, and management of biodiversity to derive sustainable benefits for present and future generations	[9]
Climate resilience is the capacity to prepare for, respond to, and recover from the impacts of hazardous climatic events while incurring minimal damage to societal wellbeing, the economy and the environment.	[10]
Perma garden: is a small-scale, high-yield, nutrition-focused instrument of food security that anyone can create close to home. A perma garden does not rely on expensive materials from outside the community; it can be successfully created and maintained using only local tools and seeds.	[11]
Food systems: the network of activities and stakeholders involved in the production, processing, distribution, consumption, and disposal of food, as well as the social, economic, and environmental factors that determine how food is produced and delivered to consumers.	[12]
Integrated crop-livestock systems (ICLS) are productive, sustainable, and climate-resilient agricultural systems compared to specialized and intensive systems. It is an agricultural practice that could play a significant role in mitigating these challenges brought by intensive systems.	[13]
Crop rotation is the practice of planting different crops sequentially on the same plot of land to improve soil health, optimize nutrients in the soil, and combat pest and weed pressure.	[14, 15]
Mulching: Mulching is the process of covering the topsoil with plant material such as leaves, grass, twigs, crop residues, straw etc. A mulch cover enhances the activity of soil organisms such as earthworms. They help to create a soil structure with plenty of smaller and larger pores through which rainwater can easily infiltrate into the soil, thus reducing surface runoff. As the mulch material decomposes, it increases the content of organic matter in the soil.	[16]
Cover cropping: A **cover crop** is a **plant** that is used primarily to slow erosion, improve soil health, enhance water availability, smother weeds, help control pests and diseases, increase biodiversity and bring a host of other benefits to your farm.	[17]
Relay cropping: Relay cropping is defined as the practice of establishing a following crop close to the harvest of a preceding crop, often by drilling the new crop between the rows of the current crop. This method allows for continuous plant coverage, enhancing soil health and weed management. Relay cropping enhances soil quality, limits weeds and pest attack, enhances the efficient use of available resources, saves money and time, utilizes residual fertility, prevents soil degradation, and thus increases farm profits.	[18]
Monoculture implies the repetitive planting of the same crop, which consumes the same nutrients from the soil, ultimately ensuring a consistent food source for the pests and diseases that feed on those crops. This leads to an increase in: Fertilizer use to ensure that the nutrients the plants need to grow are in the soil and maintain a high yield; Pesticide/herbicide use to get rid of "undesirable" species.	[15]

Biochar is a stable form of carbon which is obtained through the transformation of wood materials using pyrolysis or open-air combustion at a high temperature, that does not release carbon. Biochar can be *a.* applied as a soil amendment and in livestock production.	[19]
Animal welfare: The practice of prioritizing the health and well-being of animals being raised.	[20]
Carbon Sequestration= the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.	[21]
Silvo-pasture: A form of agroforestry that integrates trees into pastures for grazing animals.	[21]
Productive Use of Energy refers to activities that generate income, increase productivity, enhance diversity, and create economic value through the consumption of electricity.	[22]
Agroforestry is a collective term for land management systems where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately integrated with agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence.	[23]
Soil health*:* those capable of supporting adequate production of biomass (food and fibre) for human needs, while maintaining other ecosystem services, such as climate regulation or biodiversity conservation.	[24, 25]
Mixed cropping, typically a mixture of legumes and cereals or tuber crops, is a common practice in marginal agroecological environments, which fulfils a variety of functions, including complementary use of growth factors, such as soil nutrients, light, and water; reduced pest and disease incidence, reduced soil erosion, more total biomass production, more yield stability, and more household food security.	[26]
Circular agriculture: focuses on using minimal amounts of external inputs, closing nutrient loops, regenerating soils, and minimizing the impact on the environment. If practised on a wide scale, circular agriculture can reduce resource requirements and the ecological footprint of agriculture. It can also help ensure a reduction in land-use, chemical fertilizers and waste, which makes it possible to reduce global CO_2 emissions	[27]
Soil Organic Carbon: The Measurable carbon concentration of organic matter in soils.	[28]
Vermicomposting is a process in which the earthworms convert the organic waste into manure rich in high nutritional content.	[29]

Introduction

Global food demand is projected to increase by approximately 50% by 2050, placing unprecedented pressure on agricultural systems. Currently, food production contributes nearly 10% to the global economy. However, this growth comes at a significant environmental cost. Agricultural expansion is responsible for about 80% of global native habitat loss [30], while the sector accounts for 70% of freshwater withdrawals. Moreover, the global food system contributes an estimated 34% of greenhouse gas (GHG) emissions [30]. As a result, agriculture has become the leading driver of ecosystem degradation, biodiversity loss, and climate change [30].

The modern food system is increasingly threatened by these environmental impacts. At the same time, rapid population growth is intensifying the urgency for more sustainable agricultural practices. Conventional farming methods have led to widespread soil degradation, water pollution, and biodiversity loss, with far-reaching consequences for environmental health, human well-being, and food security [30]. The scale of degradation has reached a point where sustaining current systems is no longer sufficient. Instead, there is a pressing need to restore and regenerate the natural systems that underpin life on Earth [30,31]. Today, more than half of the world's agricultural land is degraded, resulting in annual productivity losses estimated at $400 billion and posing a serious threat to global food security [30]. There are hidden costs associated with producing food, so-called externalities. These costs are typically not paid for by producers or accounted for in the final price of products but instead passed on to society. Globally the hidden costs of agricultural production systems exceed $10 trillion (10% global GDP), with environmental costs alone equating to $2.9 trillion. Environmental costs include greenhouse gas emissions, land use change (e.g., deforestation), unsustainable water use, and pollution linked to nitrogen emissions from fertiliser and manure entering surface water and the air [32].

Social costs not factored into the price of food it rather includes poverty and undernourishment. This includes poverty among people working in food and agriculture with low wages and poor working conditions, as well as lost productivity because people are unable to work at full capacity due to undernourishment. Globally, these social costs add up to $500 billion, or 4% of all hidden costs [30]. According to FAO, the biggest hidden costs not reflected in the price of food are health-related, fuelled by unhealthy diets of ultra-processed foods high in fats, salt and sugars. These diets contribute to obesity and malnutrition, as well as so-called 'lifestyle' related non-communicable diseases, together costing societies a total of $9 trillion in hidden health costs [32].

Large-scale industrial agriculture is among the most damaging contributors to this crisis. Practices such as intensive tillage, monocropping, and excessive chemical use degrade soil health, undermining its ability to function as a vital carbon sink [30,31]. Healthy soils play a critical role in capturing and storing carbon, thereby helping to mitigate climate change [31]. In contrast, conventional agriculture relies heavily on synthetic fertilizers and pesticides to boost yields and control pests. While effective in the short term, these inputs often lead to long-term environmental harm, including soil degradation, water contamination, and damage to ecosystems and wildlife [30,31]. Additionally, monoculture farming reduces biodiversity and increases vulnerability to pests and diseases. Over 400 pest species have developed resistance to pesticides, while populations of natural pollinators, particularly bees, are declining at alarming rates—raising serious concerns for future food production [30]. Conventional agriculture also depends on intensive irrigation and mechanization, both of which contribute to greenhouse gas emissions. The sector consumes approximately 70% of global freshwater resources, while agrochemicals frequently leach into soils and contaminate groundwater, rivers, lakes, and oceans [30]. In response, sustainable agriculture has emerged as an approach aimed at mitigating these negative impacts and safeguarding natural resources for future generations [30,31,33].

Regenerative Agriculture goes a step further by prioritizing the restoration and enhancement of ecosystem health. It focuses on strengthening the natural processes that support soil, water, biodiversity, and human communities. Rather than exploiting natural systems, regenerative agriculture emphasizes working in harmony with them, maintaining ecological balance and resilience [30,31,33]. Core practices include cover cropping, crop rotation, mulching, reduced tillage, crop-livestock integration, agroforestry, and the use of organic inputs including vermicomposting, all of which contribute to improved soil health and ecosystem functionality [30,31].

Smallholder farmers—especially in Sub-Saharan Africa and South Asia—face a complex set of interrelated challenges that perpetuate low productivity, poverty, and environmental degradation. Decades of unsustainable land management, inappropriate fertilizer use (both overuse and underuse), and limited soil stewardship have led to widespread soil degradation, nutrient depletion, and erosion, undermining productivity and food security while creating ecological stress [34]. Traditional farming practices, often constrained by limited resources and information, continue to drive soil degradation and declining yields. These challenges are further compounded for women and youth, who face additional constraints such as limited access to credit, high transaction costs, and insufficient collateral [34,35].

Regenerative agriculture presents a promising pathway to transform food systems while restoring natural ecosystems. By enhancing soil health, regenerative practices enable soils to sequester carbon, thereby contributing to climate change mitigation. Practices such as cover cropping, crop rotation, mulching and reduced tillage minimize soil disturbance and enhance carbon storage [30]. Furthermore, integrated approaches—including the use of organic fertilizers, optimal external inputs, crop-livestock integration, Perma Garden for nutrition and income—collectively address productivity, environmental, and socio-economic challenges [36,37].

On the other hand, there are still key barriers on the adoption of sustainable agricultural practices which include limited access to climate-smart and context-specific agricultural technologies, supportive policy for regeneration, weak extension services, and underdeveloped market systems that hinder the adoption of sustainable practices [34]. In addition, knowledge gaps in areas such as Integrated Soil Fertility Management (ISFM) and precision nutrient management restrict the implementation of evidence-based solutions [34,35]. Therefore, understanding the basic principles and practices of Regenerative Agriculture and leveraging global experiences are very important to adopt context specific practices by the developing countries. Accordingly, the main objectives of this review study are:

- To examine global experiences, adoption trends, and emerging movements in regenerative agriculture and assess their contributions to sustainable agri-food systems transformation and food security in low-income countries.
- To synthesize and disseminate evidence on regenerative agriculture pathways, practices, enabling environments, and contextual applications to inform scientific discourse, policy development, and future research in low-income countries.

Characteristics of Conventional and Subsistence Agriculture:

Globally dominant forms of agriculture that have emerged post-World War II, here termed Conventional Agriculture (CA), have become highly industrialized, often utilizing inputs and practices that are non-renewable and unsustainable [38]. Conventional agriculture is a significant contributor to environmental damage and soil health, including biodiversity loss and disruption of biogeochemical nutrient flows (including Phosphorus and Nitrogen) [38,39].

Globally 75% of earth's lands are substantially degraded in large part due to conventional farming and land use patterns [39]. Modern, intensive agriculture is more susceptible to growing demographic and climate crises. The human population is expected to rise to over 10 billion by 2050 and global leaders are demanding up to a 70 percent increase in food production [39]. On the other hand, the existing food systems, already account for 19-29% of global greenhouse gas emissions (GHG) [39]. The largest source of agricultural emissions are industrial cropping practices that disturb and degrade soil health, including tillage, monocropping, fallowing, and heavy use of chemicals like fertilizers, pesticides, and herbicides and fossil fuel [40]. Another source of agricultural emissions comes from industrialized animal production facilities called confined animal feeding operations, also known as feedlots [40].

Soil Degradation

Soil degradation, which includes things like erosion, nutrient depletion, and loss of organic matter, is a big problem around the world [41,42]. The declining effectiveness of nitrogen fertilizer, with recovery rates falling from 80% in 1960 to less than 30% by 2000, is a sign of global degradation. In SSA, using fuelwood causes deforestation, and then farming on fragile land speeds up the degradation of the soil. To fix low yields, we need to use adaptive intensification and soil restoration methods [43].

Agriculture is the primary cause of land use change globally: 50% of the world's habitable land is used for agriculture, of which 77% for livestock and 90% of tropical deforestation is linked to agricultural expansion. Deforestation causes CO_2 emissions, accelerating climate change. Globally, 62% of IUCN (International Union for Conservation of Nature) threatened species are adversely affected by agriculture, primarily due to land use change and the use of chemical pesticide. Globally, 35% of our crops rely on Insect pollinators, yet over 40% of all insects are declining, and a third are endangered. Similarly, 20% of agricultural lands have insufficient ecological integrity to provide ecosystem services in support to food production. Worldwide, 90% of crop varieties and 50% of domestic animal breeds have been lost – which reduces agricultural resilience [35,43,44].

Freshwater withdrawals mean major rivers have insufficient environmental flows to maintain aquatic biodiversity, threatening ecosystem integrity and undermining blue food production [33]. Fertilisers are the main cause of N_2O emissions; 300x more potent than CO_2 and remains active for 100+ years in the atmosphere. Emission have increased 30% in past 30 yrs [33,35,37].

The agriculture sector is also highly linked to social and health issues, largely driven by wider food system inequalities: 500+ million farmers & fishers live in poverty, 800 million people are hungry every day, while 2 bn people are overweight or obese [37]. Globally, lack of dietary diversity is a primary cause of diet-related disease [37,41].

Current agricultural practices contribute to 1/2 of annual GHGs emissions which is accelerating climate change and in turn will reduce crop yields: Methane, N_20 and CO_2 emissions accumulate in atmosphere and create a heat-reflective layer. Climate change is expected to decrease crop yield e.g. maize yields in EU by 22%; wheat yields in Southern EU by 49% [37]. Globally, 78 per cent of the world's poorest people remain reliant on agriculture and agriculture contributes to about a quarter of global climate emissions [37,45].

Approximately one-third of all food produced globally is either lost or wasted [45]. This has significant implications for food security, climate change, and the economy at large. Globally one in ten people remains malnourished despite the volume of food produced, while food loss and waste contribute to 8-10% of global greenhouse gas emissions and result in economic losses of up to USD $1 trillion per year [45].

Globally, agricultural activity is linked to 70 percent of the projected terrestrial biodiversity loss between 2011 and 2020 [46]. A reduction in global crop yield is estimated up to 3–12% by mid-century [46,47]. To address these all-round challenges mentioned above, Ethiopia has launched a comprehensive Fertilizer and Soil Health Roadmap. According to this roadmap, soil degradation, which is estimated to cost the national economy between $1 billion and $4.3 billion annually in terms of agricultural production and ecosystem services loss [48].

An estimated 41 per cent of Ethiopia's cultivated land is affected by soil acidity, alongside widespread nutrient depletion, land degradation, alkalinity, acidity, and declining organic matter [48]. In the highlands alone, annual grain losses are estimated at 1.5 million tons, equivalent to approximately 2 to 6.75 percent of the National Agricultural GDP [48].

With the rising population and climate crisis, agriculture has had no choice but to alter its course. Regenerative agriculture is quickly becoming the answer to this problem as farmers question their conventional methods. As more case studies emerge showcasing the success of regenerative farming practices both environmentally and economically, the more attractive the transition becomes [40].

Principles, Practices and Adoptions levels of Regenerative Agriculture (RA):

Regenerative Agriculture is an alternative to conventional production that has the capacity to produce high quality food, improve profit margins, sustain biodiversity, restore degraded land and soils, and store carbon, with minimum dependency on external inputs [38-40].

According to a review of 286 best practice projects in 57 countries, over 37 million ha of land with the cooperation of 12.6 million farmers, transitions to organic, agro-ecological, and resource-efficient practices led to an average yield increase of 79% by integrating different regenerative agriculture practices [39,40]. In systems where only crop diversification was introduced, yields were 20-60% higher than monoculture systems under the same management [39].

The practice of RA can be positioned within a wider movement of ecological, or stable methods of food production (e.g., organic, biodynamic) and was popularized in the early 1980's by Robert Rodale (Rodale 1983). While overlapping with many more established agricultural practices, including conservation agriculture the terminology of "regenerative agriculture" has gained traction in more recent times [49].

Regenerative agriculture is an outcome-based food production strategy that improves farm productivity and financial success while nurturing and restoring soil health [49,50]. It consists of a variety of methods supported by cutting-edge technologies that can address the problems brought in by climate change while preserving the environment of the land [11,12]. Regenerative agriculture is an improvement over conventional agriculture that uses less water and other inputs, stops land deterioration, and preserves the environment. It increases farms productivity and profitability while preserving and enhancing soil, biodiversity, climate resilience, and water resources [50]. Regenerative agriculture aims to increase farmer livelihoods, produce enough nutrient-dense food for the world's population, help mitigate climate change by storing carbon in soil and lowering greenhouse gas emissions, restore threatened biodiversity, enhance natural habitats, as well as prevent further deforestation and grassland conversion [50].

For example, research in Argentina, India, and the West African Sahel has found that crop yields can be increased by 20–70 kg/ha for wheat, 10–50 kg/ha for rice, and 30–300 kg/ha for maize with every 1000 kg/ha increase in soil organic carbon (SOC – a component of soil organic matter) around plant roots. One global meta-analysis on maize and wheat show that yields were greater with higher concentrations of SOC with proper Carbon: Nitrogen ratio [37].

Regenerative agriculture has several benefits for farmers, for example, no-till techniques, enhance soil health by feeding subsurface microbes and expanding the variety of species that live

Table 1: Regenerative Agriculture Principles and Practices.

Principles	Practices
Minimize tillage	Zero-till, reduced tillage, conservation agriculture, controlled traffic
Maintain soil cover	Mulch, cover crops, permaculture
Build soil C	Biochar, compost, green manures, animal manures
Sequester carbon	Agroforestry, silvo-pasture, tree crops
Relying more on biological nutrient cycles	Animal manures, compost, compost tea, green manures and cover crops, maintain living roots in soil, inoculation of soils and composts, reduce reliance on mineral fertilizers, organic agriculture, permaculture
Foster plant diversity	Diverse crop rotations, multi-species cover crops, agroforestry
Integrate livestock	Rotational grazing, holistic [Savory] grazing, pasture cropping, silvo-pasture
Avoid/reduce pesticides use	Diverse crop rotations, multi-species cover crops, agroforestry
Encouraging water percolation	Biochar, compost, green manures, animal manures, holistic [Savory] grazing

Source: [57,58]

beneath the surface. The microorganisms in the soil help plants obtain minerals and create phytochemicals linked to disease prevention and longer lifespans as soil health improves [50].

By reducing and eventually eliminating the use of chemicals and synthetic fertilizers, regenerative farmers and ranchers encourage biodiversity by protecting soil microbes, beneficial insects, and waterways [51]. For example, the herbicides often used to kill weeds on croplands have the harmful side effect of killing soil microbes and beneficial insects like earthworms, honeybees, and ladybugs [51]. Instead of applying herbicides to kill weeds, regenerative growers plant cover crops, and multiple crops on the same unit of land. By letting cover crops grow, then cutting them and leaving the plant residues on the land, they reduce the likelihood that weed seeds will germinate [51]. This helps the farmers reduce their use of herbicides. Similarly, instead of spraying harmful insecticides to kill insects, regenerative growers' plant diverse crops. Crop diversity attracts beneficial insects that keep pests at bay, which helps farmers reduce their use of harmful pesticides and insecticides [51].

Reduced Direct Emissions from Soil

Healthy soils store carbon, but they need to be cared for properly, so they don't turn into carbon sources [52]. Practices that improve soil health can stop carbon from leaving the soil. A meta-analysis from 2016 found that tilled soils let out 21% more organic carbon (OC) than untilled soils [45]. This difference grew to 29% in soils that had been damaged [53]. A more recent study that lasted six years found that no-tillage and reduced tillage cut OC emissions by 51% and 45%, respectively [54]. Soils that are healthier are also less likely to erode, which helps keep carbon in the soil [45].

Regenerative agriculture also encourages farmers and ranchers to reintegrate animals into cropping systems in ways that nurture relationships within the ecosystem, further improving biodiversity on the land and potentially helping improve soil health [55]. For example, animals like sheep, goats, chickens, and cows can graze fields and eat weeds, reducing the need for toxic herbicides, and their manure can be used as a natural soil amendment, reducing the need for synthetic fertilizers [55]. Using multiple regenerative practices simultaneously—like cover cropping, crop diversity, and animal integration— allows farms and ranches to reduce the use of harmful chemicals and support the natural ecosystem, which both ensures a robust yield and protects biodiversity [55]

In addition to the cost savings from reducing or eliminating the use of harmful chemicals and fertilizers, regenerative growers add more sources of revenue by diversifying what and how they grow [56]. Instead of selling one or two commodities for income, which is what happens with the dominant industrial agricultural model, regenerative practitioners can pool incomes from animal products and multiple crops, as well as from farm stays, agritourism, and value-added goods [55,56]. Regenerative agriculture also encourages growers to sell into a variety of markets, including not only larger contract buyers but also markets that connect farmers and consumers, such as Community-Supported Agriculture (CSA) shares, direct sales to consumers, farmers markets, food hubs, restaurants, and public institutions like schools. In other words, regenerative growers do not put all their eggs in one basket for the market [56].

Research suggests that we could sequester more than 100% of current annual carbon emissions by switching to farming practices that help take carbon out of the atmosphere and returning it to the soil [30,38,40]. According to Rodale institute, in the regenerative farming trials conducted in Iran, no tilling and low-input corn production using composted manure resulted in an increase in soil carbon by 4.1 metric tonnes per hectare a year, in just two years [30]. This was in comparison to the 0.01 metric tonnes for the paired tilled system using synthetic fertilizers. It was noted that land for growing plants used for food for human consumption, when shifted to regenerative models, could sequester more than 40% of annual emissions, an estimated 21GtCO_2 [30,34]. Healthy soils absorb more water and the increase in organic content which in turn increases yields. Minimized tillage results in more carbon capture, reducing greenhouse gases in the atmosphere. Regenerative agriculture is not just about farming techniques; it is a profound understanding of our interconnectedness with nature [30,39,56]. Soil supports a complex network of worms, fungal hyphae and microscopic air pockets surrounded by aggregates of soil particles. Disturbing this with ploughing and doses of fertilizers or sprays will be a setback for the system [30]. A variety of plant species also attracts insects and animals that form beneficial symbiosis. Agroforestry which would entail incorporating trees into the system offers multiple benefits that include improve soil health, increased yields and productivity and providing habitat for wildlife [30,39].

As previous studies from Germany, Denmark, and the US showed, Regenerative agriculture is most impactful when adopted at the landscape, rather than individual farm level [46]. This tailored landscape-level approach, rooted in systems-level coordination, is needed to achieve scale, catalyze demand, and overcome challenges throughout the value chain. This allows for flexibility, where mechanisms are customized to the unique circumstances of each landscape, as well as broadened economic and environmental impact. Therefore, the recommendation is to start with the farm and grow to the land scale level to leverage the cross-border additionalities and avoid cross boarder effects from conventional practices. Regenerative Agriculture as sustainable agri-food system does have its own principles and practices. It is more of context specific and holistic in nature. According to 57 & 58 the major RA principles and practices are summarized and presented in Table 1 below.

Regenerative Agriculture vs Organic Agriculture

Regenerative Farms

The primary goal is to revitalise and enhance the natural ecosystems of the land. Regenerative practices aim not only to sustain current conditions but to actively regenerate soil health, biodiversity, and overall ecosystem resilience. These farms prioritize soil health by employing practices such as cover cropping, crop rotation, and reduced tillage. These methods help build soil organic matter, retain moisture, and promote beneficial microbial activity, ultimately enhancing soil structure and fertility [59].

Organic Farms: Organic farming primarily focuses on avoiding synthetic pesticides, herbicides, and genetically modified organisms (GMOs) to promote soil and water quality, as well as human health. The emphasis is on preventing harm rather than actively restoring ecological balance. While organic farms also prioritize soil health, regenerative practices often go beyond organic standards. Organic farms may use tillage methods that can disrupt soil structure, whereas regenerative farms aim to minimize such disruptions [59].

Research by the International Union for Conservation of Nature (IUCN) indicates that Regenerative agriculture could sequester over 6 billion metric tons of carbon dioxide equivalent and increase soil organic carbon by 20% in Africa by 2040. Additionally, agroforestry systems demonstrate significant soil organic carbon improvements compared to conventional agriculture. On the other hand, in sub-Saharan Africa, soil nutrient depletion remains severe [60]. Farmers lose an estimated 40 kilograms per hectare of Nitrogen, Phosphorus, and Potassium annually without adequate replenishment [60]. AGRA's regional analysis shows that over 70% of Africa's arable land suffers from poor fertility, soil acidity, or low organic matter. These conditions restrict fertilizer responsiveness and limit yield potential – a fundamental barrier to food and income security by smallholder farmers in less developed countries [60].

Degraded soils reduce the quantity and quality of food produced. Crops grown in micronutrient-poor soils often lack essential nutrients such as zinc and iron, contributing to hidden hunger, particularly among children and women in low-resource settings. For example, the application of ISFM practices that restore soil health can double farm productivity and result in farm incomes increasing up to 50% [60].

Regenerative Agriculture on Vegetable Production in Kenya and Ethiopia by World Vegetable Centre (2020-2025) on 471.1 hectares of land indicated that farmers benefited from vegetable sale with a total of USD 3,184,739 and created 61,438 casual and decent jobs for smallholder farmers with significant adoption rates of regenerative practices [61]. Similarly, Regenerative Agricultural Practices for Improved Livelihoods and Market Systems (REALMS) (2020-2024) implemented in Kenya and Rwanda indicated that 10,716 smallholder farmers involved in Regenerative Agriculture practices. Out of the total number of farmers who participated, 57% increased their crop yield [61]. On the total land under regenerative agriculture, 40% of the plots showed improvement in soil health, and 63% of the SMEs showed improved revenues [61].

The Agri-food Programme for Integrated Resilience and Economic Development in the Sahel (Pro-ARIDES) (2021-2030) in Mali, Burkina and Niger indicated that the program reached 953 villages through Regenerative Agriculture practices in which 568,225 farmers benefited from the interventions. The result indicated that 17% of the participants improved their diets, 63% diversified their income sources, 23% increased their income. In total, 69% of the total farmers engaged in Regenerative agriculture adopted climate-smart technologies and practices [61].

Regenerative agriculture can deliver substantial and enduring productivity gains in the poorer parts of the world. One study examined the impact of 286 projects in 57 poor countries [62]. The projects included integrated pest and nutrient management, conservation tillage, agro-forestry and rainwater harvesting. These projects increased productivity on 12.6 million farms while improving critical environmental services [62]. The average crop yield increase was 79%, while the African projects showed a 116% increase in crop yields. All crops showed water use efficiency gains. The projects included crop improvements, agro-forestry and soil conservation, conservation agriculture, integrated pest management, horticulture, livestock and fodder crops [62]. Crop yields more than doubled on average over a period of 3-10 years. Project Drawdown estimates that if regenerative agriculture increases from 221 million hectares to 332 million hectares by 2050 (current adoption is approximately 11.84 million hectares based on organic agriculture land), this could result in a total cumulative reduction of 14.5 GtCO2e to 22.3 GtCO2e by 2050 [62].

In Rodale Institute's FST (Farm System Trial), soil carbon levels increased more in the manure-based organic system than in the legume-based organic system, presumably because the manure stimulates the soil to sequester carbon in more stable forms. The study also showed that soil carbon depends on more than just total carbon additions to the system, because cropping diversity or carbon-to-nitrogen ratios of inputs may also have an effect [65]. The answer of the research output lies in the decay rates of soil organic matter under different management systems. The application of soluble nitrogen fertilizers in the petroleum-based system stimulates more rapid and complete decay of organic matter, sending carbon into the atmosphere instead of retaining it in the soil as the organic systems do.

The energy use efficiency

the agricultural sector accounts for 30% of global energy consumption and requires power for food production, storage, transportation and processing and reducing postharvest losses. The infrastructure used to power food systems is heavily reliant on fossil fuels, accounting for at least 15% of fossil fuel use globally but Sub-Saharan Africa, energy use for Agriculture is far behind the global average [66]. On the other hand, there are abundant renewable resources in those low-income countries which could have been used to alleviate these challenges in Africa. To show the effect of tillage on energy use efficiency in agri-food system, using conventional and regenerative agriculture practices on corn production is summarized and presented in Figure 1 below.

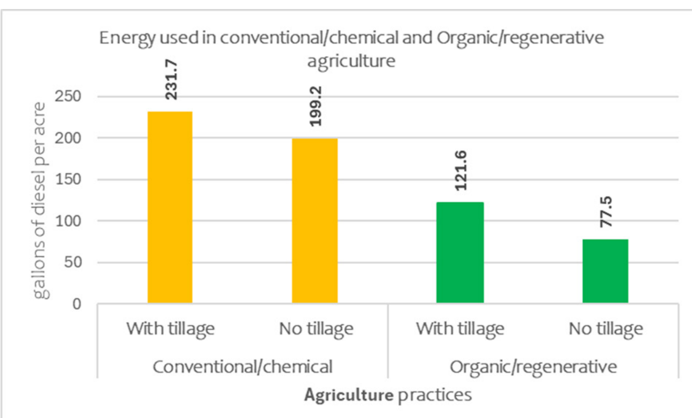

Figure 1: Energy Used in Different Corn Production Systems in the US by Rodale Institute.
Source: [65]

Greenhouse Gases

The three most abundant greenhouse gases are Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). Total greenhouse gas emissions are often expressed in units called carbon dioxide equivalents, or CO_2e [67]. This unit puts all greenhouse gas emissions on a level field by expressing them in terms of the amount of carbon dioxide that would have the same global warming effect. More than 2/3 of total emissions come from carbon dioxide alone: 37.5 $GtCO_2$. The research finding by [67], by comparing conventional practices and organic system indicated that yield can be increased by 40% in times of draught, farmers can earn 3-6x greater profit, improve soil health with 45% less energy use when using organic methods. Similarly, the Carbon emissions reduced by 40% with no atrazine, a toxic chemical, into waterways [67].

In a nutshell, regenerative agriculture is concerned with soil restoration, biodiversity enhancement, climate resilience, increased and stable production, and the development of a holistic ecosystem and ecosystem services. As such, regenerative agriculture appears to be a promising path for overcoming 21st century challenges and advancing sustainable agriculture development [67].

Regenerative Agriculture Experiences in Africa

Severe land degradation in Africa negatively impacts nearly half of all productive land, affecting well over 650 million people. Practices resulting in land degradation have removed almost a third of the world's arable land from production over the last 40 years, and sub-Saharan Africa (SSA) is experiencing the brunt of this crisis. Continued inaction to improve and restore land could lead to further losses of USD 4.6 trillion over the next 15 years in Africa [69].

To restore degraded lands, regenerative agriculture practices such as crop diversification, tree planting, reduced tillage, mulching, crop-livestock integration, and water conservation techniques spur benefits for both agribusinesses and society. These techniques improve yields via increased soil nutrient and organic content, reduced soil erosion and improved water retention [71].

Businesses in SSA already reap the rewards of regenerative agriculture in programmes reaching over 100,000 farmers, with yield increases from 68% to 300%. Companies such as Anheuser-Busch InBev (AB InBev), Linking Environment, Agribusiness & Forestry (LEAF) Africa, Nespresso, Olam, Touton and Twiga Foods have already implemented regenerative agriculture programmes in the region [74]. Olam has seen an 80% increase in cotton lint yields through regenerative techniques, which include mulching and crop rotations [73]. Touton boosted annual yields by 68% through its agroforestry programme, using shade-tree planting [69]. Through a Nespresso training programme, the individual farmers who have fully embraced regenerative practices such as pruning and rejuvenation contributed to 300% yield increases [73]. Within just a few years, regenerative farming systems in SSA could greatly increase yields and reduce input costs to farmers. The annual savings to farmers across SSA may be as high as USD 17 billion by 2040 by adopting Regenerative Agriculture practices and could support 5 million jobs by the same year [69].

Regenerative farming generates significant crop yield improvements in SSA. There is compelling evidence that the implementation of regenerative farming practices leads to substantial yield gains across SSA. A range of peer-reviewed academic articles on the use of RA practices in East Africa have seen yields increase by 100% in comparison to non-regenerative practices [70]. Impacts are particularly strong in semi-arid regions of West Africa, which benefit especially because of the temperature and precipitation patterns they already face from climate change [69]. In the Sahel, the adoption of farmer managed natural regeneration (FMNR) was associated with increases in crop production ranging from 35% to

170% [70]. As examples, FMNR adoption in Senegal is associated with millet production increase from 300 to about 770 kg of millet per hectare [71]. In East Africa, agroforestry initiatives produced significant crop yield increases compared to nonregenerative monocultures [70,71]. In Malawi, maize production increased from 320 to about 550 kg per hectare with climate smart agroforestry [70].

Household annual income can increase by up to USD 150 per year through crop diversification. Farming households using regenerative agriculture may supplement their income through diversification, such as agroforestry, crop diversification, rotation, cover cropping, crop-livestock integration or milling and log production. The sale of tree products from FMNR and agroforestry systems can increase revenues up to USD 4517 per hectare per year [69].

Regenerative practices increase topsoil retention, nutrient retention and overall soil health. Regenerative practices increase soil nutrients, not only soil organic carbon, but also nitrogen, phosphorus and micronutrients. Soil organic carbon is estimated to increase by 20% and nitrogen by 24% if regenerative practices are deployed [70]. This increases not only in the top layer but also in subsoil to 50 cm depth or more, which has implications for both crop and tree growth, as well as for ecosystem services [69].

Regenerative agricultural practices can improve conditions for vegetation growth and decrease water requirements by improving soil water holding capacity. As regenerative agriculture practices increase organic matter and cover soil, more water can be stored and retained in the soil, as rainwater infiltration is enhanced and runoff reduced [73,74]. As organic matter increases in the soil, soil moisture increases as well, improving the availability of water to plants: a 1% increase in organic matter in the soil profile can store up to an additional 150 m^3 of water per hectare. In addition, soil cover and the avoidance of mechanical soil tillage reduce water loss. All these factors reduce water requirements for crops by up to 30% [73].

Restoring soils can reduce soil erosion by 30%, avoiding the loss of essential nutrient-rich top-soil. When soil is restored and healthy, soil erosion caused by water and wind is substantially reduced. Covering and protecting soil with mulch also greatly lowers soil erosion, increase moisture retention and overall soil condition improvement for the microbiotas. While precipitation runoffs can be up as high as 45% on some soil types, adding soil cover can eliminate soil erosion compared to monocultures [73].

Regenerative agriculture at the farmer level reduced costs which could be equated up to USD 150 per hectare per year, which may translate into savings of USD 17 billion per year in SSA if regenerative practices are adopted at scale. The environmental benefits generated through regenerative agricultural practices can substantially reduce the farm inputs requirements, as well as the associated costs. As soil becomes healthier and soil erosion reduces, the soil is rich of essential nutrients, thus reducing the inputs and costs of fertiliser which is another advantage which is attributed from regenerative agriculture practices [71]. On the other hand, increased soil water retention reduces irrigation requirements, and increased biodiversity below and above ground which in turn increases ecosystem functionality, hence reducing pest management costs or disaster related costs [69].

Economic and production impacts

The illustrative regenerative scenario has been chosen to give 13% higher crop production in 2040 than the BAU scenario. Innovation in agricultural technology and crop breeding continues to increase crop yields in the baseline scenario. However, the changes to innovation costs, nitrogen take-up efficiency, water availability and other aspects of regenerative practices would accelerate these yield increases and take them further [71]. By 2030, Sub Sahara Africa crop yields will increase by 17% (an extra 4%) if regenerative scenario fully operational. By 2040, the uptake of regenerative agriculture practices might increase yields by 65%, a 13% higher yield relative to the BAU result in 2040 [71].

In the regenerative agriculture scenario, food prices may be lower by 16-24% in 2040 compared to food prices in BAU. Currently, households in Sub-Saharan Africa spend on average about 50% of their income for household food consumptions [69]. As food output increases, it relieves pressure on food prices and households will spend a lower share of their income on food and households can invest on other productive activities.

Regenerative systems increase per capita calorific intake by 16% and improve nutrition for society at large as well as for smallholder farmers compared to the conventional system [70]. Daily calorific intake per capita may increase across Sub-Saharan Africa by 2040 up to 16% more when agriculture is regenerative which is from about 1,860 to almost 2,400 calories per person per day from 2020 to 2040 [70]. Calorific intake from more diverse crops (mainly pulses, fruits, vegetables, nuts and roots) is 16% higher compared to BAU, and 47% higher compared to 2020 [70]. Farmers adopting agroforestry or FMNR for instance can not only harvest a wide range of on-farm forest products (fruits, nuts and pods) during the dry season but also improve dietary diversity as trees and crops are simultaneously grown alongside other crops [75].

Increased uptake of organic cropland management in SSA might increase the soil carbon stock 4.4 $GtCO_2e$ by 2040 [73]. Sequestration rates for different crop practices vary, with reliable meta-analysis results showing between 1.1 tCO_2e/ha/yr for cover cropping to 3.7 tCO_2e/ha/yr for perennial grains [74]. If 50% of cropland were to be managed through regenerative practices by 2040, the carbon stock in soil could increase in sub-Saharan Africa by 4.4 $GtCO_2e$, or around 220 $MtCO_2e$ per year [74].

A comparative evaluation was made to evaluate RA practices and adoptions at two counties (Embu and Makueni) in Kenya [78]. The RA practices uptake varied between the two counties depending on what was most appropriate. Farmers combined different RA practices within the same plot depending on the perceived benefits.

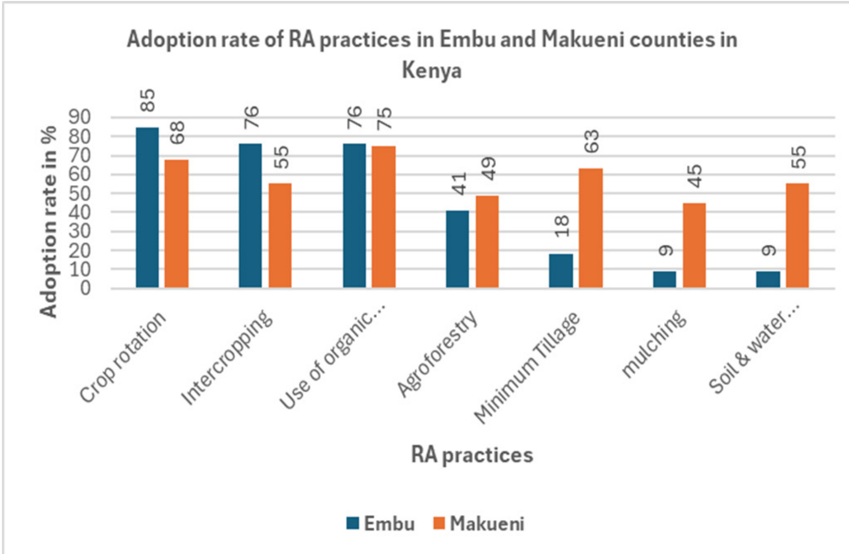

Figure 2: Regenerative Agriculture Practices Uptake in Embu and Makueni Counties in Kenya
Source: [78].

In Embu County, crop rotation, intercropping, and use of organic fertilizers was adopted by 85%, 76% and 76%, respectively, of the 10,239 farmers who were included in the program. The result in Makueni county on the other hand indicated that, cover cropping, manuring and crop rotation uptake was at 79%, 75% and 68%, respectively of the 14,917 farmers who were reached by the project. This business case confirms the effectiveness of RA practices in building farmers to adapt to the effects of climate change [78]. The difference in the adoption rate between the two counties are indicators for the variation in the context. In general the success in uptake of the RA practices was attributed to:

- Farmers adopted different RA practices based on the benefits associated with the practices and their appropriateness to the agro-ecological zones. This showed that the farmers had gained knowledge from the project interventions and were applying in their farms.
- There is no one size fits it all – different RA practices were combined within the same plot to have effect and this varied from farm to farm and from location to location. This showed that we cannot recommend one practice to be the best but instead we should recommend the farmer to practice what is applicable in their farms for regeneration.
- RA practices like minimum tillage, mulching, soil and water conservation, use of cover crops, have proved to build farmers resilience in areas which received low rainfall as farmers who had practiced such, harvested with little rainfall as opposed to those who did not use the practices.
- The VBA (Village Based Advisors) model was effective in disseminating principles and practices of RA to communities due to the underlying trust between VBAs and farmer groups.
- For the community-based extension system like the VBA model to be sustainable, there is need to house it within the mainstream government extension system.
- Access to markets is a strong driver for farmers to adopt RA practices as they become more confident on the off taking of their produce.
- Involvement of research institutes in providing the appropriate inputs for and knowledge to farmers in different ecological zones improved outputs.
- Use of digital platforms reduced the costs to serve farmers through extension and market linkages.
- Support from the county governments was critical to convening farmers and gaining their trust and commitment to adopt RA practices. So, the two counties experience indicated that the role of the local political wing and decision makers are highly important.
- For details of the adoption rates of RA practices at the two counties the following is summarized and presented as Figure 2.

Pros, and cons of Regenerative Agriculture

Pros as per [43,44]:

- Soil health improvement: regenerative agriculture practices such as minimal tillage, cover cropping, and crop rotation help to build organic matter in the soil, improve soil structure, and increase soil fertility, and water retention.
- Biodiversity enhancement: by incorporating diverse crop rotations, integrating livestock, and creating habitat for beneficial insects and wildlife, regenerative agriculture can promote biodiversity on farms.
- Climate change mitigation: practices such as carbon sequestration in soil, agroforestry, and rotational grazing can help to capture and store carbon dioxide from the atmosphere, thus mitigating the effects of climate change.
- Reduced input dependency: regenerative agriculture often relies less on synthetic fertilizers, pesticides, and herbicides, reducing the environmental impact and the potential health risks associated with these inputs and biodiversity loss.
- Increased resilience: by improving soil health and biodiversity, regenerative agriculture systems tend to be more resilient to extreme weather events, pests, and diseases.
- Water Conservation: Improves water retention and reduces

runoff.

- The rising political will to go for Regenerative Agriculture practices in some parts of the world including Ethiopia through development of relevant strategies (Agroecology and Forest Development Strategies), and establishment of national platform called Action Coalition for Sustainable Regenerative Agriculture Commercialization lead by Ministry of Agriculture.

Cons as per [22,35,42,44]**:**

The adoption or promotion of regenerative agriculture on a large scale faces many trade-offs and depends on the objectives of farmers and governments. Understanding the extent of these trade-offs is important to form policy recommendations and design necessary incentive schemes to assist the adoption when large-scale adoption is desired. Future rigorous empirical studies are needed to carefully gauge the extent of these trade-offs in practice for regenerative agriculture to be recommended as a solution to challenges under climate change.

- **Temporary yield drops and Technology Adoption for Smallholder Farmers**: During the first years of transition, as soil biology and structure recovery needs time, crop yields may fluctuate or even decline with limited adoption.
- **Context-dependent effectiveness:** Benefits are not uniform: performance depends strongly on soil type, climate zone, and local ecological, social, economic conditions.
- **Complexity of implementation**: Effective regenerative farming demands good understanding of ecology, without the proper know-how, the intended environmental benefits may not be verified.
- **Lack of standardized metrics or evidence:** There is still limited long-term, standardized data; this makes it hard to predict reliably the environmental outcomes in all cases.
- **Knowledge and skill requirements:** regenerative agriculture requires a deep understanding of ecological principles and adaptive management techniques which may involve additional training and education for farmers.
- **Market access and premiums:** while there is growing consumer demand for regeneratively produced food, accessing premium markets and communicating the value of regenerative products to consumers can be challenging for farmers.
- **Limited research and data**: despite increasing interest in regenerative agriculture, there is still a need for more research and long-term data to fully understand its benefits, limitations, and scalability".
- **Access to Resources:** Many farmers may lack access to the resources, such as training, technical support, and financial incentives, needed to transition to Regenerative Agriculture. Addressing these resource constraints is essential for widespread adoption including to renewable energy access.
- **Policy and Regulatory Barriers**: Existing agricultural policies and regulations may not always align with the principles and practices of Regenerative Agriculture. Reforms and adjustments to policies are necessary to create an enabling environment for these practices to flourish.
- **Lack of Insurance and Income-Smoothing Mechanisms:** The lack of insurance or other income-smoothing mechanisms can deter farmers from taking any uncertain investments even when the investments are beneficial for them in the long run.
- **Lack of Institutional Support**: Weak local institutional support in guiding scientific farming in Africa poses a significant challenge to the widespread adoption of regenerative agriculture in Africa

Conclusions

The global agricultural system produces approximately 23.7 million tonnes of food each day, with an estimated daily value of USD 7 billion. Most of this production—about 82%—comes from cereals, roots, tubers, fruits, and vegetables. Worldwide, there are more than 600 million farms, most of which are small, family-run operations, typically cultivating less than two hectares and concentrated in low-income countries.

Despite its critical role in food production and livelihoods, agriculture places significant pressure on natural resources. Around 50% of the Earth's habitable land is used for agriculture, and the agri-food system is responsible for approximately 90% of tropical deforestation, contributing substantially to carbon dioxide (CO_2) emissions and accelerating climate change. Additionally, nearly one-third of global soils are degraded, largely due to intensive farming practices, with the impacts being more severe in low-income countries where soil health is already vulnerable. Biodiversity is also under threat. Agriculture affects 62% of globally threatened species, mainly through land-use change and the widespread use of chemical pesticides. At the same time, about 35% of global crop production depends on pollinators, yet over 40% of insect species are in decline, with one-third at risk of extinction.

There are hidden costs associated with producing food, so-called externalities. These costs are typically not paid for by producers or accounted for in the final price of products but instead passed on to society. Globally the hidden costs of agricultural production systems exceed $10 trillion (10% global GDP), with environmental costs alone equating to $2.9 trillion. Environmental costs include greenhouse gas emissions, land use change (e.g., deforestation), unsustainable water use, and pollution linked to nitrogen emissions from fertiliser and manure entering surface water and the air. Industrial agricultural practices—including heavy reliance on synthetic fertilizers and pesticides, large-scale monocropping, and intensive tillage—are key drivers of these challenges. They contribute to increased greenhouse gas emissions, degrade soil and water resources through nutrient pollution and erosion, and significantly reduce ecosystem biodiversity.

These interconnected challenges call for a holistic and sustainable transformation of agricultural systems. Regenerative agriculture offers a promising pathway forward. It is an integrated farming approach that seeks to restore and enhance ecosystems by improving soil health, increasing biodiversity, and strengthening resilience to climate change. Key benefits include carbon sequestration, improved water management, enhanced ecosystem services, reduced dependence on external inputs, and better livelihoods for farmers through cost reduction and improved productivity and nutrition. Global experiences demonstrate that regenerative agriculture practices can be effectively adapted to local contexts, providing scalable solutions that particularly benefit smallholder farmers in low-income countries. Most study findings indicated that, involvement and collaboration of value chain actors including policy makers are very important in the implementation of regenerative agriculture practices, and adoptions.

Recommendations

Based on the above facts and figures, the following recommendations are suggested:

- Mainstream RA in the existing farming system by reorienting extension services to local contexts.
- Moving towards an outcome-based framework with standardised metrics for measuring and assessing regenerative agriculture practices and adoptions to identify and innovate site-specific interventions, as there are no universally accepted frameworks so far.
- Build more robust evidence bases and involve smallholder farmers in action research as leaders.
- Ensure an Integrated Approach Across Research and Development and allocate funds for that for sustainable adoption.
- Support farmers in a transition to regenerative agriculture through knowledge, resources, and financial incentives.
- Promote regenerative practices in aggregate like cover cropping, crop rotation, reduced tillage, crop-livestock integration so on to bring additive effects.
- Mainstream RA principles and practices in the national curriculum.
- Integrate RA into national agricultural strategies (e.g., climate-smart agriculture frameworks).
- Redirect subsidies and incentives toward soil restoration, carbon storage, composting, and agroforestry.
- Invest in farmer training and local innovation through extension systems and demonstration farms including Farmers Field School.
- Establish regenerative value chains with market incentives (carbon credits).
- Mobilize climate finance and development aid for regenerative transitions.
- Reduce external input use and enhance regenerative inputs.
- Encourage investment in RA by leveraging Public-Private Partnership modalities.
- Navigating Regulations and synergies between RA and PURE applications and experiment their nexus.
- Enhance collective actions among value chain actors through establishment of Multistakeholder platforms at different level including policy dialogue forums.
- The focus of the intervention should be more of landscape instead of individual farm level for broader adoption, scalability, extensive learnings, sustainability of the interventions, and system level change.
- Empower women, Youth, and People with Disabilities in Regenerative agriculture practices.

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