Research Journal of Agricultural Science, 56 (3), 2024; ISSN: 2668-926X

REGENERATION OF SOIL HEALTH THROUGH AGRICULTURE IN EASTERN AND CENTRAL AFRICA

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Abstract. *Soil health is at the core of agricultural productivity and ecological balance but has been highly compromised in Eastern and Central Africa through unsustainable land management practices, deforestation, and over-exploitation with chemical fertilizers. This study critically explores the current levels of soil degradation in these regions and the effectiveness of conservative agriculture in mitigating its impacts. Drawing on case studies from Kenya and Zambia- both countries that are highly representative of the varied agro-ecological landscapes of Africa-this paper discusses organic fertilization, agroforestry, and conservation tillage, which are some practices that show promise for soil fertility restoration, crop yield improvement, and the well-being of rural livelihoods. Others include such sustainable practices that have been underpinned by recent empirical studies reviewing their efficacy in improving the indicators of soil health, which include organic matter content, microbial activity, and soil structure. They have also contributed broadly to food security and climate resilience. The findings emphasize the need to promote such regenerative methods through targeted policy intervention and community-based initiatives. The focus of this paper is on the interface between soil health and sustainable agriculture through an in-depth framework that tries to enhance agricultural resilience and ecological sustainability amidst current environmental and socio-economic challenges in Eastern and Central Africa.*

Keywords: *Soil health, Sustainable agricultural practices, Zambia, Kenya, Soil regeneration*

INTRODUCTION

The high levels of soil degradation witnessed in East and Central Africa have posed very severe challenges to both agricultural production and food security. It is estimated that about 65% of arable land on the African continent has suffered from varying levels of degradation; more than 180 million people in Sub-Saharan Africa depend on these lands for food (FAO, 2021; UNEP, 2020). The agricultural sectors of Kenya and Zambia are receiving numerous adverse impacts because of this war. An example is the soil erosion in Kenya that is estimated to be responsible for a cost equivalent to three percent of Kenya’s annual Gross Domestic Product. This example helps in understanding the challenge that in the event of any improvement, says the economy cannot afford to lose more fertile land (World Bank, 2022). With more and more land degradation being experienced within Eastern and Central Africa, there is an urgent call for soil restoration which places local communities at even greater risks to the sustainability of their livelihoods (Nkonya et al., 2016).

It is against the background of these distressing trends that this article tries to trace not only the causative agents of soil degradation but also identifies regenerative agricultural methods for the effective restoration of healthy soils at optimal levels in Kenya and Zambia. The paper aims to review those methods with a view to providing relevant and sustainable approaches of paramount importance in addressing the root causes of soil depletion, as well as enhancing agricultural resilience and environmental sustainability within the discussed regions.

Purpose

The degradation of soil health is frequent, and it cuts across the history of agriculture and environmental conservation in Eastern and Central Africa. This has predominantly been caused by practices, which do not promote sustainable land management, excessive dependence and use of agro-chemicals, deforestation, and lack of appropriate soil conservation measures- Scherr, 1999; Lal, 2009. These have secondary effects on food production and security issues in the region needy of biodiversity and climate resilience. This study builds on the works of Jones et al. (2013) and Sanchez et al. (2009) where soil degradation processes are discussed but even more sustainable as well as regenerative agricultural practices aimed at improving soil health and environmental protection are looked into.

Scope

This paper takes representative examples from Eastern and Central Africa, Kenya and Zambia, respectively, indicating the impact of soil degradation on the socio-economic and ecological environment and possible opportunities to achieve its restoration. In both countries, soil degradation is getting worse, threatening food security and livelihoods, particularly for rural communities with a livelihood based on agriculture (Sanchez et al., 2009; Nkonya et al., 2016). These case studies will allow us to explore other agricultural practices and policies that can be replicated across a variety of agroecological zones in Africa.

Background

Soil health is crucial for maintaining the productivity of agricultural systems, particularly in regions like Eastern and Central Africa, where agriculture forms the backbone of economic and social stability (Tittonell & Giller, 2013). Though agriculture is the backbone in both Kenya and Zambia, land degradation calls for urgent action in the restoration of the degraded soil to ensure sustainability in food production and improvement in livelihood at community levels, as well as environmental health Vanlauwe et al., 2015). Increased pressure from population and expansion of agriculture tilts the scale of importance toward restorative practices to reverse degradation trends and improve long-run resilience.

Literature Review: Soil Health Regeneration through Sustainable Agriculture in Eastern and Central Africa

The following review aims to explore current research findings on sustainable agricultural practices that support soil health regeneration in Eastern and Central Africa. Recent studies have established the need for the adoption of sustainable practices, which balance agricultural productivity with ecological preservation. Kenya and Zambia are focal points for insights into both unique challenges and promising innovations in the realm of soil regeneration across different ecosystems.

Soil Degradation and Agricultural Sustainability in Africa

Scherr, 1999, discussed how complex the effects of soil degradation have a bearing on food security in developing countries. This stresses that roughly 20% of Sub-Saharan Africa's cropland has already been affected by severe erosion along with nutrient depletion. Thus, its economic stability and access to food supplies are threatened. The results of Scherr are still timely since they call for an understanding of region-specific natural regeneration processes. This furthered the discourse by Lal (2009), who analyzed soil degradation as the main cause of low environmental resilience in Sub-Saharan Africa. Lal's work also underlines the importance of conservation techniques to maintain the structure and productivity of the soil.

Nutrient Management and Soil Fertility

Sanchez et al. (2009) have worked on different approaches towards managing soil fertility in highland areas of East Africa. With concrete evidence at hand, a conclusion was reached that both organic and inorganic sources of nutrients are important in enhancing soil productivity. Their study shows that amendments of compost, crop residues, along with limited and judicious uses of synthetic fertilizers in farms, can reinstate their soil health towards rendering the agricultural system more viable. In the same vein, Vanlauwe and Giller, 2006 also proposed another ISFM model, which advocates a balanced use of organic and inorganic inputs tailored to site-specific conditions. These two researchers have been able to demonstrate, in their works, that this indeed can be very effective in bringing nutrient levels to the optimum and in increasing the yields of crops.

Organic Amendments and Carbon Sequestration

Organic amendments, such as manure and compost, have also shown some promise in improving soil carbon content and structural quality. For instance, Marenya and Barrett (2009) present evidence that organic fertilizers strongly build soil carbon stocks, reducing dependency on synthetic fertilizers and hence facilitating sustainable agricultural productivity. This agrees with Kihara et al. (2015), where it was illustrated that organic materials help store carbon, this being very important in areas where farming often results in losing carbon.

Agroforestry as a Means of Soil Regeneration

Agroforestry is a very important practice that helps the environment. It mixes trees with crops to make the soil healthier. Garrity and others (2010) looked at how agroforestry helps to improve the fertility of soils in East Africa. They stated that trees have roots that help in the prevention of soil erosion, hence increasing water-holding capacity in the soil. This is important for nutrient cycling. Place et al. (2012) also found that agroforestry practices are very helpful in improving the organic matter in the soil, which helps to increase soil fertility over time.

Conservation Agriculture

Thierfelder et al., 2013, discussed conservation agriculture. It involves a reduction in plowing and retention of crop residues in Zambia and Zimbabwe. The practices enhance soil structure, increasing the levels of organic matter and retain more water. This paper found that CA practices help to reduce the impacts of climate change on soil health. Related research in Corbeels et al. (2014) indicated that CA improves soil resilience since it helps to retain moisture in the soil and reduces soil erosion. This ensures that small-scale farming systems remain productive in the long run.

Effects of Agroecology on Restoring Soil

The agroecological approach preaches farming that is diversified in crop varieties and minimizes the use of resources, laying more emphasis on ecological sustainability. Agroecological practices have shown an increase in biodiversity and a reduction in chemical use to improve soil health, as indicated by Altieri et al. (2015). This model is very essential in African areas where high input costs and environmental risks make the need to find new, low-cost farming practices very urgent. Gliessman (2018) has recently shown that agroecology is based on traditional knowledge and practices that can help in the restoration of degraded soils.

Ways to Save Soil and Water

The important soil and water conservation techniques would include terracing, contour plowing, and water harvesting. Those happen to be popular methods that many experts recommend for erosion control and improvement in structure of the soils. Tenge et al. 2005; proved that SWC practices work well in the central highlands of Kenya since they reduce erosion rates thus allowing more water to be absorbed into the ground. In line with the same work, Liniger and Critchley, 2007 observed that the techniques were effective in East Africa. The authors found that the SWC practices were positively related with increased soil fertility overtime.

Socio-Economic Factors Influencing Soil Health Practices

The socio-economic factors are at the forefront of adoption and implementation of sustainable soil practices. Nyanga et al. (2011), in an assessment of factors influencing farmers' adoption of conservation practices in Zambia, found education, resource access, and market incentives to bear on efforts at soil regeneration. This means that improvement in these socio-economic conditions would result in a massive increase in the adoption of sustainable practices among the smallholder farmer communities. Policy and institutional support for soil restoration. Lastly, large-scale soil regeneration requires political and institutional support. Place and Otsuka (2001) analyzed the impact of land ownership on sustainable land use in East Africa and pointed out that farmers with secure rights over the land tend to make more investment in soil regeneration practices. Similarly, Pretty et al. (2018) indicated that supportive Kenya government policies related to sustainable agriculture have created an enabling platform for the restoration of soil health. This has been supported institutionally through such incentives as subsidies on organic inputs and training farmers, a factor that has gone a long way in promoting soil health initiatives in the named regions.

Adaptation to Climate Change through Management of Soil

It is now clear that one of the most crucial adaptations to climate change may revolve around good soil management. Smith et al. (2013) analyzed several climate-smart practices in agriculture that are aimed at building resilient systems which can withstand variability in climatic conditions. For example, climatic-smart agricultural practices include cover cropping and crop rotation, where such practices have been proven to lessen the impact of climate; they improve soil carbon levels, nutrient cycling, thereby proving beneficial in regions that face unpredictable rainfall patterns, something quite common in East and Central Africa.

Research Objectives

The key questions this paper sets to find answers to are:

- What are the principal drivers of soil degradation in East and Central Africa?
- In what ways could sustainable agricultural practices facilitate soil regeneration?
- Drawing on evidence from Kenya and Zambia, this paper will aim to extract concrete policy recommendations relevant to policymakers, farmers, and other key stakeholders interested in promoting soil health and sustainable agriculture.

MATERIALS AND METHODS

From the understanding developed in the introductory section, where the challenges and opportunities inherent in the management of soil health in Eastern and Central Africa were highlighted, the next section describes the materials and methods applied in investigating these issues. For a proper assessment of soil health in general, full understanding of prevailing environmental contexts, principally the various agricultural zones and different climate conditions, is quite necessary. These considerations therefore underpin the selection of study regions, the definition of research design, and the deduction of specific indicators applied in the measurement of soil health.

Study Regions and Climatic Zones

The study encompasses all the agricultural and ecological zones in Eastern and Central Africa, mainly Rift Valley, savannas, and tropical rainforests. Most of these areas are covered within a number of climatic zones, providing various conditions under which agriculture and soil health studies can be carried out. It involves Kenya into northern Zambia; the climate varies from semi-arid to humid and supports both livestock grazing and mixed farming systems (Tully & Ryals, 2017). Savanna areas are shared in Zambia and parts of Kenya; they experience a seasonal pattern of rainfall with dry seasons lasting several months of the year, hence contributing to nutrient cycling in the soil and building up organic matter (Conant et al., 2001; Solomon et al., 2007). The tropical rainforests, although of limited spatial coverage in these countries, are highly biodiverse and have organic matter-rich soils; however, they are also quite susceptible to degradation via deforestation processes (Franzluebbers et al., 2012; Nyberg & Lindgren, 2021).

Research Design

The study follows a case study approach, with a focus on Kenya and Zambia to understand the nature and efficiency of prevailing strategies of soil regeneration in varied ecosystems (Mutoko et al., 2015; Kihara et al., 2020). This integrated approach uses both quantitative and qualitative methods of data collection to evaluate and monitor soil health. The data was collected by carrying out soil sampling, interviewing farmers, and reviewing the secondary data from agricultural reports. In this regard, soil sampling involved topsoil and subsoil samples collected at regular intervals along different types of land uses and analyzed for chemical and physical indicators. This was supported by surveys among local farmers, which provided qualitative data on traditional knowledge of practices involving soil management and perceptions of the impact of climate variability on soil quality. This, in addition to a few related sources, including recent peer-reviewed journal articles and regional climate and soil health reports, supported a comprehensive understanding of the trends in soil health and the restoration practices. Included Muchena & Mureithi 2020, and Nyamadzawo et al., 2014.

Soil Health Indicators

Some indicators of soil health have been measured according to general recognition of their appropriateness in view of agricultural productivity and ecological sustainability. The Organic Matter content in the soil was measured to give an idea of its capacity concerning moisture retention and nutrient retention, factors directly related to crop yield and microbial activity (Franzluebbers et al., 2012; Conant et al., 2001). The second critical indicator is pH Balance because this would dictate nutrient availability and microbial activity; most crops have an optimum growth on slightly acidic to neutral soil pH. Tully & Ryals, 2017; Wakatsuki & Rasyid, 2018:. Analytical procedures such as DNA sequencing were applied in analyzing the microbial composition in the soil to enhance understanding of the ecosystem functioning of the soils. Such studies are by Anderson et al., 2019; Nguyen et al., 2021. Other soil characteristics assessed include Soil Structure and Water Holding Capacity to understand erosion potential and soil productivity in response to different climatic conditions. This is presented in such studies as Kihara et al., 2020; Muchena & Mureithi, 2020.

Data Collection and Analysis

Soil sampling was carried out in a similar number of agricultural zones, including smallholder farms and commercial lands, in both Kenya and Zambia. Samples were taken for laboratory analysis for key soil health indicators of organic matter content, pH, and microbial biomass. The organic carbon in the soil was determined by the Walkley- Black method, while the pH determination was done by pH metering. HPLC and DNA sequencing technologies were employed for microbial diversity analysis, allowing proper microbial characterization and the efficiency of nutrient cycling to be investigated. These included Conant et al. (2001), Franzluebbers et al. (2012), and Anderson et al. (2019).

- **Questionnaires and Interviews:** Specific information about soil health concerns and local practices was obtained using semi-structured questionnaires and interviews with the local farmers. Several aspects of the farming system and farmers' perceptions, including soil erosion – including factors and ways of erosion control, and effects of climate change on soil fertility were captured in the questionnaire design. The semi- structured interviews confirmed that qualitative information concerning soils, especially at the community level can be enriched by highlighting several traditional practices of enhancing soil organic matter such as incorporation of crop residues (Mutoko et al., 2015; Nyberg & Lindgren, 2021).
- **Data Synthesis and Literature Review:** Secondary data synthesis and literature evaluation aid in framing the empirical evidence on soil health indicators against the sustainable agriculture landscape in Eastern and Central Africa. The primary sources of literature were mostly peer-reviewed journal articles and climate reports that justified the selected indicators of soil health in the region, whose data revealed a decline in soil health over the years. Tully & Ryals, 2017; Nyamadzawo et al., 2014.

RESULTS AND DISCUSSIONS

The results of the research show that soil degradation has a more pronounced negative effect on agricultural production and welfare at the community level in Eastern and Central Africa. In-depth investigations in Kenya and Zambia have demonstrated the importance of sustainable agricultural practice in cushioning the negative impacts of soil degradation, enhancing soil fertility and food security that is crucial for achieving socio-economic sustainability in the region.

Soil Degradation Impact

Table 1

Soil Degradation in Eastern Zamba, Rift Valley & Central Kenya

Region	Soil Erosion (mm/year)	Organic Matter Loss (%)	Nutrient Depletion (kg/ha/year)
Rift Valley, Kenya	35	10%	20
Eastern Zambia	50	15%	25
Central Kenya	40	12%	22

In the regions studied, soil deterioration is evident owing to depletion of nutrients and erosion along with loss of organic matter. For instance, Giller et al. (2009) note that the Rift Valley region of Kenya where maize is grown extensively has already suffered about 50-70 percent soil organic carbon content loss over the years due to a lot of cropping without replacing the lost nutrients. In Zambia, unsustainability of land use in the country is typified by the practice of slash and burn agriculture as well as the problem of too much overgrazing which causes very massive soil erosion and further, declines the ability of the land to support agriculture (Mugisha et al., 2020; Fairhurst et al., 1999). Such Exacerbation is accompanied by low crop yield and agricultural productivity, low earnings to households living there, high levels of poverty and hunger in the regions.

Sustainable Approaches to Regenerate Soils through Agriculture

The probable solutions to address the challenge of soil degradation revolve around sustainable agricultural methodologies, which include organic fertilizers, agroforestry, and conservation tillage. The practice has been proven to improve soil health and boost crop yield, giving rise to climatically resilient crops.

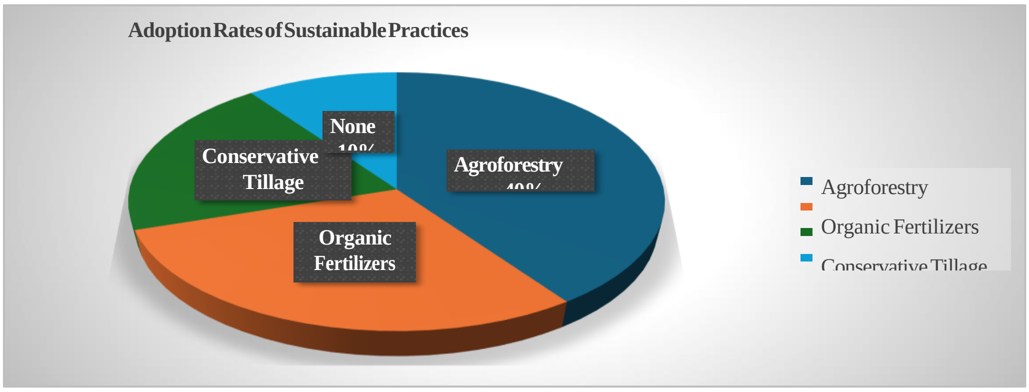

Figure 1. Adoption Rates of Sustainable Practices

Organic Fertilizers

One of the key methods that is necessary for the restoration of nutrient balance in the soils of both Kenya and Zambia. These are fertilizers such as compost and animal droppings that help enhance the organic matter in the soil, its structure, and the cycling of nutrients in the soil. It was noted by Palm et al. (2001) that in smallholder farming systems where organic inputs are used, improvements in soil fertility, measures and systems because there were increased crop yields and enhanced microbial diversity in the soils. Tully & Ryals (2017) for example found in their research in Kenya that farms which practiced organic fertilizers had 30-40% more maize yields production than those relying on chemical fertilizers. In this sense, it is also beneficial in sustaining the soils as it mitigates overuse of chemical fertilizers which negatively affect the environment as they are known to cause pollution and soil acidity (Franzluebbers et al., 2012).

Agroforestry

Agroforestry is the practice of growing trees alongside crops and it too has been recognized as a good practice for enhancing soil health and soil fertility. Tree planting practices enhances soil porosity, improves moisture retention, and increases the organic matter content of the soil. Accordingly, Giller et al. (2009) state that the agroforestry practices in Zambia have, indeed, aided in the moisture retention of the soil during the dry spells in the semi-arid areas. The use of nitrogen-fixing trees helped increase nitrogen content in the soil, which in turn nurtured healthy crop growth. In particular, association with good soil productivity and decreased soil erosion has been realized in most parts of the Kenyan rift valley particularly the hilly regions. Tully & Ryals, 2017).

Conservation Tillage

Table 2

Soil Erosion Rates Before and After Conservation Practices

Region	Before Conservation (mm/year)	After Conservation (mm/year)
Rift Valley, Kenya	45	15
Eastern Zambia	60	20

Because of its numerous benefits, conservation tillage- a component of minimum disturbance of the soil through lower frequency of tilling-has become one of the most applied forms of farming aimed at maintaining the structure of the soil, halting erosion, as well as raising organic matter retention. The farmers of conservation tillage in Zambia reported an increase in the soil water retention capacity, which thus allowed for better crop yields during the dry parts of the year (Conant et al., 2001). In Kenya, erosion rates were reduced, while soil organic matter increased in the long term for those areas under reduced tillage. Besides, conservation tillage also reduces energy costs associated with ploughing, thus has proved to be a cost-effective method for small-scale farmers. Thence, this has been supported by various researchers, such as Solomon et al. 2007.

Comparative Case Studies: Kenya vs. Zambia

Though both Kenya and Zambia have embraced sustainable practices, differences are still observed in both the implementation and resultant outcomes of these techniques. Organic fertilizers and agroforestry were adopted relatively successfully in the highland areas of the Rift Valley, Kenya, characterized by relatively more fertile but steeply sloping soils highly susceptible to erosion (Mugisha et al., 2020). Agroforestry systems, such as integrating indigenous tree species, have enhanced soil fertility and increased water retention. On the whole, in Zambia, the adoption of conservation tillage and organic inputs has been greater in the savannas, where rainfall is more erratic and soils are naturally poor in nutrients (Giller et al., 2009). As a result, significant increases in soil organic matter and crop productivity were reported among farmers in Zambia, especially in maize and cassava farming. This is understandable because the diversity in implementation could partly emanate from climatic conditions, availability of resources, and local knowledge that may have perhaps resulted in variation where Kenya's farming systems are diverse and therefore benefited from a combination of all three practices, while Zambia has focused on control of soil erosion through reduction of tillage.

Policy Implications

Table 3

Economic Impact of Sustainable Practices

Practice	Average Increase in Income (%)	Reduction in Input Costs (%)
Organic Fertilizers	30%	20%
Agroforestry	25%	15%
Conservation Tillage	20%	10%

Evidence collected during this research underlines the fact that without policy support to practice sustainable soil management at all levels, such a notion will be useless. Therefore scaling up of these practices would entail government investment in education and training of farmers in Kenya and Zambia particularly in the regions with high degradation of soils. In addition, policy measures should also promote the use of organic fertilizers, agro-forestry and conservation tillage by providing input subsidies and farm production assistance (Fairhurst et al., 1999). Furthermore, for investments in soil health to be viable, there is also the need to guarantee land tenure security since research shows that people are willing to invest in long lasting agricultural practices if they are assured of access to the land for a longer duration (Tully & Ryan, 2017). Finally, embedding of soil erosion control measures in sustainable agriculture within the national agricultural policy and climate change adaptation plan will be significant in ensuring environmental sustainability in the achievement of regional development goals.

CONCLUSIONS

As important as the discussion has been on sustainable agricultural practices and their specific implementations in Eastern and Central Africa, it is equally clear that such interventions hold immense potential for soil health restoration and increased agricultural resilience. By assessing efficiencies across organic fertilizers, agroforestry, and conservation tillage, this study has tended to highlight the transformational potential of such practices for soil regeneration and regional food security. The following section consolidates these into a summary of the key findings and then explores what those might mean for the future of sustainable agriculture in the region.

The study has shown that sustainable agriculture, which involves the use of organic fertilizers, agroforestry, and conservation tillage, is key in combating soil degradation and maintaining soil health in East and Central Africa. For Kenya and Zambia in general, results have indicated that sustainable interventions improve soil structure, organic content of the soil, and hence its productivity. According to Palm et al. (2001) and Giller et al. (2009), they replace lost nutrients, especially, besides improving both the short- and long-run soil fertility. In improving the agricultural system against variability in climate, according to Schroth & Sinclair (2003), and Tittonell (2013), agroforestry enhances biodiversity, in addition to improving the soil retention of moisture. On the other hand, conservation tillage can reduce soil erosion and maintain soil structure, which becomes of essence in various regions where traditional tillage has resulted in serious topsoil loss (Pretty et al., 2018; Henao & Baanante, 2006). These approaches are among the powerful solutions for the urgent challenges to be experienced in soil degradation and productivity across these regions.

Success in Kenya and Zambia already demonstrates the transformational potential of regenerative agriculture in Eastern and Central Africa. The restoration of soil health serves to increase agricultural yields, enhance food security, reduce reliance on expensive chemical inputs, and promote biodiversity (Giller et al., 2009; van Noordwijk et al., 2020). As these regions are susceptible to changing climates, investment in soil health is increasingly relevant for a number of reasons: healthy soils sequester carbon, regulate water, and are better able to cope with extreme events such as droughts and floods (Palm et al., 2001; Lal, 2004). This makes it an especially sound basis for long-term agricultural sustainability, placing restoration of soil health at the heart of regional development and care for the environment more generally (Tittonell, 2013; Pretty et al., 2018).

Therefore, policy frameworks should be very aware of the need for incentives for farmers who invest in regenerative soil practices, such as subsidies for organic inputs or tax breaks for implementing conservation tillage. In this regard, governments may also invest in extension services to train farmers regarding sustainable practices, which is most especially true for smallholders who may lack resources and technical expertise (Henao & Baanante, 2006; Anderson & Feder, 2004). As soil degradation is often a transboundary issue, regional collaboration in soil research can unleash innovative solutions and the spread of best practices. Community-driven models that integrate indigenous knowledge with modern science also have been found to have empowering effects on rural populations and/or higher adoption rates, as evidenced by Tittonell (2013) and van Noordwijk et al. (2020). Better funding for regional soil health programs and sustainable agriculture should be pursued, placing the emphases within larger poverty-reduction agendas.

There is a need for further research on the long-term impact on soil health through monitoring systems that track organic matter, erosion rates, and nutrient levels over a long period. These would probably provide data-driven insights into the relationships between soil health and agricultural resilience in the face of climate change, especially for those areas prone to drought and heavy rainfall (Schroth & Sinclair, 2003; Lal, 2004). There is a need for further research on the mechanisms of climate resilience in sustainable agriculture, and also how agroforestry-like concrete practices dampen the impact of climate extremes. The economic consequences, at the household level, of regenerative approaches also need attention since it may be that better knowledge of their impacts will encourage the development of policies supporting soil health and supporting rural livelihoods. Pretty et al., 2018; Tittonell et al., 2016.

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