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Soil health management in sub-Saharan Africa requires a landscape approach

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Abstract

Soil health is the capacity of soil to support plants, animals and humans and is central to agricultural livelihoods, food production and other environmental services. Widespread soil degradation and increasing demands from agricultural land have led to concerted research and action to reverse soil degradation and improve soil health. The common farm-level approach to soil health management and improvement can be effective and there are many documented cases of positive impact. However, in areas dominated by small farms, such as much of sub-Saharan Africa, soil health is also influenced by interactions between different farms and between agricultural and non-agricultural parts of the landscape. Hence, we propose that in these conditions a landscape approach to soil health management is appropriate. Five further propositions concern the way context, co-creation, monitoring, facilitation, and investment in soil health are different at landscape and farm levels and the consequences of these. A seventh proposition is a recommendation for updating available tools and frameworks to support landscape approaches to soil health. These propositions are hypotheses that can be confirmed, refuted or modified through research. Research in diverse contexts will generate the insights needed to refine the propositions and allow them to be used in place-based action on soil health. Together, the propositions point to a change in the common ways in which soil health is conceptualized, action on soil health is organized and research supports the effort.

1 Introduction

Soil is fundamental to agriculture and food production as well as other environmental services, including protection of biodiversity, carbon storage, and cycling of water and nutrients. However, agricultural soils are increasingly degraded, a trend driven by multiple factors including continuous cultivation and inappropriate soil management [1]. In Africa, the state of soil is a result of complex natural and human processes over a very long time [2, 3], with degradation exacerbated by the inherently old and weathered soils, the expansion of farming into marginal environments, and rising land pressure as a growing, agriculture-dependent population demands more from the land. This has prompted sustained research and policy focus, and on-the-ground action aimed at maintaining and restoring soil health across the continent.

Farmers have always managed their soil, and many traditional practices have evolved in different contexts. For example, in much of Africa, slash-and-burn long rotations were central to soil management, with fields opened up in areas of natural vegetation, cropped until fertility declined and then abandoned until it had recovered [4, 5]. Social, economic and demographic changes led to increasing demands from agricultural land and labour. These changes in turn led to changes in approaches to soil management, driven by the desire to increase production and the reduced viability of some traditional practices, for example due to limited land availability. Hence soil management became a domain of action by governments and others seeking to help and influence farming. Over time, the soil management paradigms on which these interventions are based have evolved in response to biophysical challenges, increased understanding of soil processes, and broader concerns about sustainability [6]. The earliest approaches focused on meeting crop nutrient demands primarily through fertilizer inputs. A second paradigm was developed that emphasizes the role of biological processes in enhancing nutrient use efficiency and recycling. More recently, an integrated soil fertility management paradigm has emerged, promoting the efficient use of fertilizer–especially in rehabilitating degraded soils–as a foundation for sustainable intensification. Building on this trajectory, agroecological and regenerative approaches now conceptualize soil health as a foundation of production and other ecosystem services which embody the role of soil in a broader system encompassing ecological, social, and economic dimensions [7]. The newer paradigms advocate for a systems approach and focus on how soil, as a sub-system in ecology, interacts with other sub-systems.

Given the importance of soil in supporting agriculture, rural livelihoods and ecological functions of land, it is not surprising that for many years there has been considerable research and action on soils across Africa. In addition to basic research and development of soil management recommendations, there have been numerous projects and programs involving participatory experimentation, farmer training and other extension efforts, and impact assessments. The development of context-specific recommendations, Farmer Field Schools and Farmer Research Networks (FRNs), and popular communication channels (e.g., radio and TV) have all played roles [7]. These efforts typically focus on farm-level decision-making and farmers' practices. They involve collaboration between facilitators (NGOs, extension workers, researchers) and organized groups of farmers. While positive impacts have been observed, the farm-scale focus has inherent limitations, as soil health is influenced not only by farm-level practices but also by broader landscape dynamics. Farms are nested within larger landscapes, and processes at this scale – such as erosion, water flow, and land-use patterns, which operate across farm boundaries— significantly affect soil conditions. Landscape approaches to land management that integrate ecological, social, and economic dimensions have a long history of conceptual and practice development [8]. They are now widely promoted and used [9], often by those focusing on biodiversity conservation [10]. However, interventions supporting soil health for smallholders – participatory research and action, communication, training and policies – are rarely based on landscape approaches. The recent 2024 Nairobi Declaration adopted at the African Fertilizer and Soil Health Summit, the Africa Fertilizer and Soil Health Action plan and the Soil Health Initiative for Africa Framework all recognize the importance of addressing soil health at the landscape level

[11–13]. However, the envisaged outcomes and planned actions only refer to landscapes briefly, and the supporting toolkit provides no guidance on using landscape approaches [14]. As another example, recent program to bring improved soil health to large numbers of farms in Kenya does not refer to landscapes [15].

In this position paper, we argue for a landscape perspective on soil health, presenting seven propositions supported by examples from Eastern and Southern Africa. Our aim is to raise awareness of landscape-level drivers and interventions, and to stimulate a shift in research and action agendas toward a more holistic view of soil health with multi-scale action. The paper can be seen as a multifaceted hypothesis about soil health which, like any hypothesis, should be critiqued and tested with more data. The first proposition is a statement of the need for landscape and systems approaches to soil health. The remaining six propositions relate to methods for putting the approach into practice. We provide justifications for each proposition based on both literature and field experience. Our intention in the paper is to prompt changes in practices in soil health interventions, not provide a comprehensive review of current literature. Experience, including but not limited to that described in this study, shows that appropriate actions on soil health and their impacts will be location and context specific. While our propositions are general and, we believed, applicable anywhere, detailed application will need to be place-based.

The seven propositions emerged from a workshop in Malawi in September 2024. The workshop aimed to synthesize current knowledge on soil health to inform narratives and policy debates in east and Southern Africa, adapt evidence from case study projects to develop publications and action plans, and develop a soil health framework based on research findings with relevance to smallholder farmers in Africa. The 30 participants (10 female, 20 male) participants were soil health scientists and experts in farmer and policy engagement who were involved in various soil health research activities at farm and landscape levels in east and southern Africa. The examples used to illustrate the propositions are drawn from experiences of workshop participants with projects in Uganda and Kenya, Malawi, and Zimbabwe (Table 1).

2 The framework

We use a modified version of the framework in Lehmann et al. [16] to organise and explain thinking on soil health (Fig. 1). Soil health is defined as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" [16]. It is influenced by processes that operate at various scales ranging from the plant and plot to the global level. At the smaller scales are processes that soil scientists, agronomists and farmers have traditionally paid most attention to including cultivation methods, use of fertilizers or manure, and residue retention. At the largest scale are influences such as climate, the environmental cost of fertilizer production and global phosphorus (P) availability. In between these are national policies and practices, for example those that support fertilizer use and promote other approaches to land management such as conservation agriculture, as well as the operations of large agribusinesses and agricultural educators. In this paper we focus on the landscape in relation to plot and farm and levels, so our framework does not include details at the larger scales.

For the ecological dimension, the state of soil health is determined by physical, chemical and biological properties of soil. Examples include:

Table 1 Summary of case studies providing examples used to illustrate each proposition

Case name used in text	Location	Lead organization and key partners	Context of smallholder farming system	Actions	Observed changes impacting soil health
DRYLANDS	West Pokot County, Kenya	University of Eldoret Local NGOs, community groups and local government	Seasonally arid sloping land, highly degraded and eroded Traditionally pastoralist community transitioning to mixed agriculture	Community building with farmers and others Collective action to control erosion, heal gullies, store water (e.g., sand dams) and change by-laws. Farm-level soil management with manure and compost input	Rehabilitated gullies; improved water storage; increased soil macrofauna; enhanced soil productivity and capacity to support diverse crops
FIPS	Kakamega, Busia and Bungoma Counties, Kenya	FIPS Africa, an NGO headquartered in Nairobi, Kenya	Acidic soils; striga infestation; encroachment of farms on fragile wetlands; limited extension support;	Village-based advisors and farmer research networks for farm-level soil diagnosis and intervention. Participatory mapping of landscape function and visioning alternatives	Improved soil pH and fertility. Strengthened and de-risked lime supply and use system Improved crop yield; Social capital towards shared management of landscape scale soil health challenges e.g., places zoned as acidic and wetland conservation
FRN-NGO	Vihiga, Siaya, and Busia Counties, Kenya	AGRISS, REFSO, development NGOs in western Kenya. Catholic dioceses in Kenya	Very small farms. Low soil fertility and low rainfall; striga infested	Farmer research network for farm-level soil fertility improvement and striga control. Communities identified soil health as an entry point for landscape transformation	Improved soil fertility and reduced striga weed
NAFORRI	Mount Elgon, Mbale District, eastern Uganda	National Forestry Resources Research Institute (NAFORRI) of the National Agricultural Research Organisation, Uganda	High-rainfall, steep terrain, loose soils, degraded land due to soil erosion and occasional landslides. Smallholder farming predominant livelihood. River siltation	Collective multi-stakeholder innovation platform for soil erosion control and land restoration across watersheds; capacity building of farmers on land restoration and soil management – cut-off trenches, agroforestry and land enclosures	Reducing volumes of soil collected in trenches and other signs of reduced erosion. Improved water quality

Table 1 (continued)

Case name used in text	Location	Lead organization and key partners	Context of smallholder farming system	Actions	Observed changes impacting soil health
PKWI/ATSI	Bukedea and Kumi Districts, Uganda	Popular Knowledge Women's Initiative (PKWI) a women's membership organisation and Ateker Transformation & Sustainability Initiatives (ATSI) a community development organisation	Traditional small farms with declining soil health affected by flooding, bush burning and drought. Insecurity due to cattle rustling	Large membership engaged in soil testing, creating soil health awareness, integrated soil and water management practices, changes in agronomy and use of bio-fertilizers	Improved soil fertility, soil structure and macrofauna diversity and numbers due. Poor response to soil interventions in areas with flooding and bush burning
CRS	Eight most food insecure districts in Southern Malawi: Nsanje, Chikwawa, Thyolo, Mulanje, Zomba, Machinga, Chiradzulu and Balaka (32 watersheds)	Catholic Relief Services (CRS) leading a consortium of 9 NGOs	Smallholder farming systems, steep hillsides, erosion, six-month dry season, frequent droughts, erosion during rainy season, progressing deforestation, acidic low-fertility soils	Strategic implementation of water absorption trenches, contour trenches, check dams, stone bunds, marker ridges, afforestation (incl. fruit trees), vetiver grass barriers, fire breaks, setup of community watershed committee, community capacity building on watershed management, ridge-to-valley approach	Reduced erosion and soil loss, increased soil moisture, water retention, improved soil structure, protected village and irrigation infrastructure, mitigated flash flooding, restored water tables and increased river flow volume and consistency
CBNE	Kisumu, Kenya	PHIS an R + D organisation in Kisumu, Cornell University, USA, local NGOs and community organisations	Rural areas with very small farms and declining soil health supply a large urban centre that has multiple waste disposal problems	Development of practices and social infrastructure for converting urban waste into products that can enhance rural soil health	Technical feasibility yet to have impact at scale
CIMMYT	Zimbabwe	CIMMYT, Agricultural and Rural Development Advisory Services, Forestry Commission, Environment Management Agency	Living labs – contextualised scaling of soil health varying from farm to landscape level interventions	Collective multi-stakeholder innovation platform for co-development of practices and governance mechanisms to promote soil health within the context of agroecology transition	Increased use of integrated soil fertility management using technologies such as; improved rangeland management
CAPS	Kakomo in Misuku Hills, Chitipa District, Malawi	DeTAS a development organistion Lilongwe University of Agriculture and Natural Resources	Small farms in a hilly area with degraded natural vegetation	Collective action for addressing food security and building on soil health for agroecological landscape transformation	Impacts on soil not yet assessed

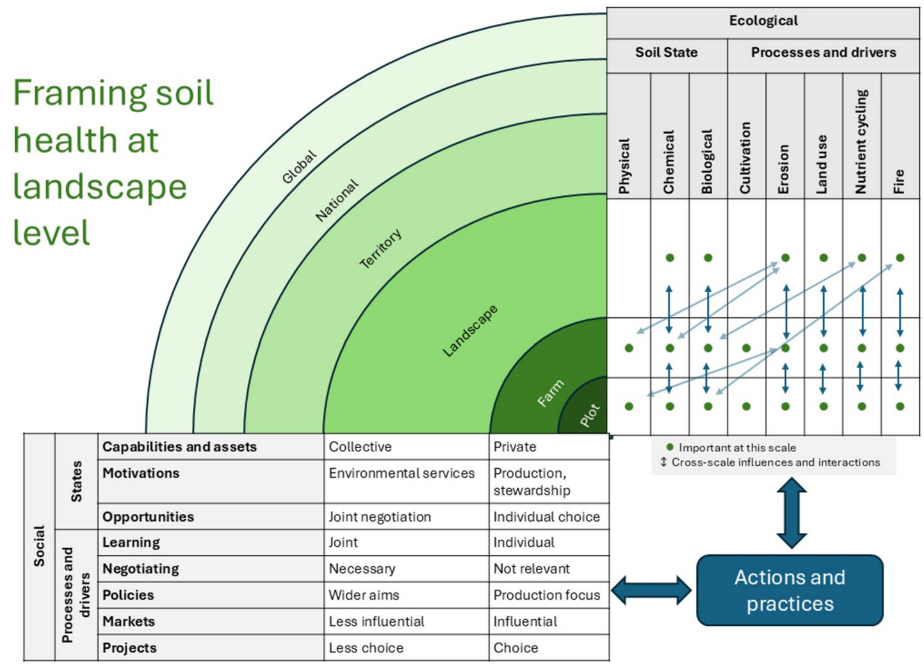

Fig. 1 The state of soil health and processes that affect it at multiple scales. Scales are shown as concentric circles around the farm and plot scale. Social and Ecological states, processes, and drivers are shown below and to the right of the scale diagram, respectively. These social and ecological parameters are described in their relation to farm, plot, and landscape scales. Social parameters are presented to highlight differences between farm and landscape levels. Ecological parameters are presented to highly interactions across scales. At lower right, actions and practices of human actors within the different scales respond to and influence the different states and processes shown. Details are not shown for global, national and territory scales as our focus is on landscapes. Arrows connecting scales are illustrative but to avoid congestion not all are shown. Based on Lehman et al. (2020)

- Physical: mineral composition, texture, moisture holding capacity, infiltration capacity, compaction.
- Chemical: macro- and micro-nutrient content and availability.
- Biological: soil macro and microfauna, plant pathogens, and weed status.

Some of the processes that can change these properties are shown in the table on the right of Fig. 1. These examples are not exhaustive and were selected as processes that are commonly manipulated by farmers and communities. Cultivation (physical disturbance of the soil) and agronomic practices such as fertilizer use are the most obvious influencing processes but there are many others. Erosion may be by rainwater or, less commonly in sub-Saharan Africa, by wind. Nutrient cycles are impacted by many different practices such as plant residue and manure use or export. Nutrient cycling is also influenced by deep-rooted perennials which can move nutrients from deeper layers to the topsoil. Fire is only important in some contexts but can have a large influence on soil health if, for example, plant residues are burnt in situ. Several of these processes are themselves influenced by land use, which includes the type of crops grown, rotations used, and the presence of non-crop vegetation in agricultural land, as well as non-cropping or non-agricultural use of land. Farmers manage plots (areas under a common set of practices) and their farm. What happens on one plot can influence others on the same farm. For example, if crop residues are retained on one plot they are not available to make compost to be used on another. Interactions and influences between plot and farm levels are shown as arrows on the right of Fig. 1.

The landscape represents a spatial scale higher than the farm. In this context, a landscape means *a contiguous area of land in which interactions relevant to soil health take place*. It may be bounded physically, such as a watershed, or socially, such as the land belonging to a village or community [17]. It consists of multiple farms as well as grazing land, woodland, wetlands, rivers and streams, settlements and the infrastructure that connects them (roads and paths). Many processes that influence soil health occur at landscape level and farms in a landscape are not independent but interact with each other and with non-farmland. For example:

- Erosion may be caused by runoff from outside the farm [18].
- Grazing of livestock can transfer nutrients from one farm to another or from grazing land to farm [19, 20].
- Fire on one farm can spread unintentionally to a neighbouring area.
- Weeds such as striga easily spread from farm to farm [21].
- Material for mulch or compost can be transferred from non-cropped land to fields.
- The areas of land cropped can change, for example when degraded soil is abandoned or fallowed and new plots are opened for cultivation [22].

In addition, the soil health of the non-agricultural land in a landscape also needs attention as it has impacts on ecosystem services.

The processes that influence soil health are managed and modified by people. At the plot and farm level, this is typically the farmer, perhaps with the involvement of several family members. Farmers choose what to do on their farms based on many factors such as knowledge, aims, motivations, and labour available. Some of these are listed as 'states' in the table in the lower left of Fig. 1. As with ecological factors, there are processes that change states, such as learning, negotiating and agreeing, and taking collective action. The second and third columns of the lower table highlight some of the differences between social states and processes when working at farm level and those when working at landscape level. Social processes are typically more complex at landscape level than farm level because of the multiple interests that need to be resolved. At landscape scale, an individual farmer may not be able to take their own decisions independently [23]. The platforms and institutions that allow people with an interest in the landscape to interact and negotiate (multi-stakeholder platforms, MSPs) become relevant. Such negotiation is complex, involving entities with different interests and positions of power such as land owners, farmers, and authorities with jurisdiction over non-farm areas. However the outcomes can be important when farmers and other stakeholders come to consensus and achieve mutual benefits, for example reducing soil erosion. At the same time there may be changes such as increased resilience to drought stress with soil health buildup, and improved water and wetland quality, so that positive synergies are built around the same landscape process. Action at landscape level is typically collective rather than individual, again requiring common understanding, aims and agreement, with political constraints and opportunities influencing process and outcomes [24].

Actions, interventions or practices that will influence soil health at landscape level bring together the social and environmental processes (lower right, Fig. 1). For example:

- Erosion control and management of arthropod pests may need collective planning and agreement involving stakeholders in addition to farmers. Such action may be supported by public investment.
- Managing grazing at landscape level may be necessary for more efficient and equitable nutrient cycling and to allow changes in cropping such as planting of trees for soil health benefits.
- The parasitic weed striga is a major soil health problem in much of Africa and effective management has to include reducing spread from farm to farm, a collective responsibility [25]. Collective action on striga has to be negotiated from a position of joint understanding of the biology and agreement that all those in the landscape will take the necessary steps.

We developed the framework specifically to support our arguments on extending plot and farm level soil health interventions to landscape levels. This is what we refer to as a landscape approach to soil health, meaning that the social and ecological dimensions represented in Fig. 1 are brought in to the visioning, planning and action on soil health. A broader framework would include the links between soil health and other social, ecological and economic dimensions of system performance. These are important because they are the drivers of soil health problems and provide motivations and entry points to improving soil health. A broader framework would also elaborate soil health processes at scales beyond the landscape. The root causes of soil health challenges may be distant from the site with market trends and trade policy influencing cropping patterns, for example [26, 27].

The propositions discussed in the remainder of this paper are all situated in this framework.

3 Seven propositions

Proposition 1. *Soil health management and improvement on farms require systemic changes involving farm and non-farm components of the landscape and a landscape approach enables this.*

Soil health management involves the biophysical and social processes illustrated in Fig. 1. Changes to any of those can have implications for other parts of the system. Since the system includes interactions both between multiple farms and between farms and non-farm areas, a systems approach at landscape level is needed. When management of soil was understood as maintaining the nutrient content of soils, the focus was on supply and use of fertilizer [28, 29]. We now understand the complexity involved in going beyond fertilizer systems and landscape approaches are needed for progress in many contexts.

In much of eastern and southern Africa, farms are small and rainfed with mixed crop and animal production [30–32]. Soil degradation is widespread with on-farm soil health conditions strongly influenced by field margins, adjacent farms, (the role of animals and management of the wider landscape [33, 34]. This is the case in the DRYLANDS and NAFORRI projects, where landscape interactions severely limit what can be achieved in soil health improvement through action at farm level.

- In DRYLANDS, low soil fertility and uneven water distribution observed on individual plots were part of broader watershed-level land degradation due to soil erosion. Improved soil health and agricultural productivity were observed after shifting focus from isolated, farm and plot-level interventions to the landscape-level. Multiple actors across the community came together to work on gully rehabilitation. This reduced erosion and improved water supply for livestock and people. The success inspired further collective action on erosion management and made investment in plot-level soil management, such as efficient manure use, viable.
- In NAFORRI a multi-actor innovation platform decided to start by addressing severe soil erosion at landscape level using mainly contour trenches, and in just two years, previously unproductive land could be farmed again.
- CIMMYT work in Zimbabwe showed how coordinated landscape action strengthens soil health outcomes. Community groups established conservation agriculture (CA) and fire guards (cleared buffer areas) that limited uncontrolled burning of grazing lands, while hay harvested from these guards was reused as mulch in CA plots to improve soil cover and moisture retention. CIMMYT also demonstrated that improved soil moisture content, that extends crop growth duration by just ten days, can be achieved with these landscape interventions and can make the difference between a complete crop failure and a normal yield.

Soil nutrients are in constant flow due to processes at different levels. Healthy system management should aim to close nutrient cycles. If there are leaky nutrient cycles at the landscape level, then farm and field level management of nutrient flows can only have limited impact on soil health.

- For FRN-NGO, and PKWI/ATSI, farm-level nutrient flow mapping revealed important inefficiencies and leaks, pointing to options for improvement at farm level. It also revealed the limitations to what can be achieved on farm alone given the interconnection of wider nutrient cycles beyond farms. Leakages and losses outside the system cannot be fully avoided and over time, farmers need to import nutrients from elsewhere within the landscape, or beyond, to keep their soils productive.
- PKWI works in areas where a traditional practice had animals grazing off farm during the day and corralled on fields at night, transferring nutrients there in faeces and urine. This practice stopped due to livestock theft, and soil health of fields declined as a result.

A major source of nutrient flow away from farm soils is through export of farm produce to markets. Reducing those losses means understanding where those nutrients go and looking for opportunities to recycle them to farms.

- o The CBNE project is working to close the loop through technologies that return nutrient exported through marketing of agricultural products from urban centres back to rural farms where they are needed.

Deposition of soil and nutrient outflows cause downstream sedimentation and pollution of water bodies and may lead to conflict and scarcity of other resources if not managed. This is an example of soil health management at farm and landscape level influencing other parts of the system.

- o Farming communities in the NAFORRI case considered tracking of water turbidity as a key indicator of their soil erosion control in the uplands.

System changes driven by soil health at landscape level can have implications in multiple sectors so need managing at landscape level.

- o In areas where FIPS is working, farmers are starting to crop valley bottoms because of moist and fertile soils. These areas had earlier been conserved for cultural reasons. Converting to agriculture affects stream flow and biodiversity and generates conflict over land rights.
- o In the DRYLANDS intervention area, many families saw migration as the only viable future, a view that has been changed by collective action on land regeneration.

Infestation of cropland with soilborne pathogens and weeds is a soil health problem. Striga has high prevalence in east and southern Africa and causes considerable crop loss. While plot- and farm-level practices to control striga are necessary and effective to some extent, there are also landscape-level factors in striga control. For example, landscape-level soil moisture is associated with striga prevalence [35] and farm-to-farm transmission of seed is an important source of infection. Similarly, other prevalent pathogens like nematodes might require a landscape approach [36],

These examples illustrate some of the ways a systems and landscape approach can influence soil health. There are also feedback loops from soil health to other system properties. Infiltration is a simple biophysical example of this, with improved infiltration being part of soil health but also influencing the landscape hydrology. The social impacts of soil health improvement, such as increased productivity, also influence the system in many ways.

Proposition 2. *Contextual factors determine appropriate soil health management practice, with different factors important at farm and landscape levels.*

At farm level, contextual factors that influence soil health and soil health management are both biophysical, such as soil type and topography, and social, such as a farmer's attitude to investment and access to inputs. These will also be relevant at landscape level. However, there are additional contextual factors that are important at landscape level. The context can be described by the current situation or norms of all the states and processes, both biophysical and social, that are represented in Fig. 1.

Hence there will be differences in context factors that are relevant to soil health management at farm and landscape levels.

Farm size influences the need for and feasibility of a landscape approach to soil health. In contexts with larger farms, an individual farmer effectively manages a landscape, so much of the complexity of landscape approaches is removed. In an example from Australia a single farm of thousands of hectares soil health was transformed using landscape approaches [37]. However, in smallholder systems in East and Southern Africa, landscape-scale interactions connect many farms and other parts of the landscape. Soil health management at a landscape scale thus overlays the management of clearly demarcated private parcels of land with a commons layer and the complexities associated with it [38]. Effective governance and collective action become a central issue in soil health improvement, something that is less important the larger the area handled by a single manager.

Land tenure type is an example of a contextual factor, largely within the 'capabilities and assets' state of our framing diagram, for which different aspects are relevant at farm and landscape levels. At farm level, land tenure has been shown to influence farmers' willingness to invest in soil health management. Owners can have a long-term stewardship approach to soil health while tenants or others with insecure tenure are interested in the short term only [39]. At landscape level, access to and tenure of land beyond the farm is also relevant.

- In the DRYLANDS context, tenure of farmed land proved to be a determinant of engagement in soil management [40]. On communally owned land, decisions to manage soil erosion and deposition strongly hinged on gaining the trust of community leaders. Negotiations can lead to all-in participation or all-out. However, in highly individualised communities where land is privately owned, such as in the FRN-NGO, FIPS and NAFORRI cases, enhancement of soil health through voluntary processes such as negotiations, incentives or building of multi-stakeholder innovation platform leads to diffuse voluntary buy-in [41]. Achieving and maintaining sufficient levels of participation across the landscape may be a challenge.

Context influences entry points for action on soil health. Effective entry points are based on issues people care about, and these may be different when focus is on farms or whole landscapes.

- In the DRYLANDS case, gullies, stream flow and sand harvesting were the landscape-level challenges that communities cared about, and these provided the entry points for work on land care and soil health management.
- In Malawi, CRS leveraged community cohesion around drought, flood damage, and soil erosion to drive landscape-level vegetation restoration and conservation, which in turn strengthened water security and increased soil health benefits.

Proposition 3. *Co-creation and negotiation of soil health interventions at landscape level must include stakeholders in addition to farmers and their different interests, power and influence have to be managed.*

The principle of co-creation, which shifts how knowledge is generated, integrated and applied, is well established for situations that need context specific and localized actions [42]. Development of interventions or practices for soil health management at farm level often involves farmers who have local and practical knowledge, working with researchers who bring in scientific and global knowledge that can support the learning and negotiating processes as well as better local understanding of ecological states and processes (Fig. 1). When a landscape approach is used then it is not only interested farmers who need to be engaged, but also other actors. They have diverse interests and perspectives and there are complex power relations between them. Landscape level interventions can have implications for all farmers in the landscape, not only those who choose to engage, as well as for non-farmers. Hence soil health interventions need co-designing and negotiating through some form of multi-stakeholder platform (MSP) in which priorities are jointly identified and trade-offs considered (Fig. 1). MSPs require careful attention to power and influence, as unequal capacities and differing levels of authority can shape whose voices are heard and whose interests prevail. MSPs bring together farmers and groups such as local government officers, cultural institutions, fertilizer dealers, extension workers, researchers and non-governmental organisations, each with their knowledge and institutional mandates [43]. Government officers on MSPs can play a key role of communicating local contexts to inform broader government plans and connecting local efforts to existing technical and financial resources.

Locally led MSPs are more likely to ensure that interventions are grounded in local priorities, knowledge systems and governance structures, thereby enhancing their relevance, legitimacy, and likelihood of long-term impact. Locally led strategies also help shift the balance of power away from externally driven agendas towards approaches that build on community agency and collective decision-making. Landscape-level decisions such as the introduction of by-laws can affect all land users, including those not directly engaged, and locally driven processes help to securing broad-based ownership and compliance, ultimately improving the sustainability and effectiveness of landscape-scale soil health interventions. All farmers in a landscape may be impacted by decisions made, such as introduction of by-laws controlling grazing or fire, and hence need an opportunity to contribute to those decisions.

Soil health is influenced by ecological processes, land-use dynamics, socio-economic drivers, governance structures, and cultural practices so transdisciplinary approaches are needed. Communication about action by credible soil health communicators is a necessary part of building the alliances on which MSPs depend [25]. Co-creation uses local knowledge and there may be additional holders of knowledge relevant at landscape level.

- FRN-NGO found different and unique knowledge and understanding of soil health management among farmers of different villages in Nyando and Homa Bay Counties.
- NAFORRI worked through a MSP to combine knowledge of farmers, extension workers, landlords, local government administrators, village cultural and religious leaders, and scientists in setting up soil erosion structures and monitoring their effectiveness. Values and uses of the data collected differed among stakeholders. MSP

members from the district local government enlisted government technical expertise and financial support for local soil erosion control efforts.

- FIPS found that interests and the envisaged outcomes, such as improved condition of water and recovery of wetland biodiversity, among the upland communities in river bank management were strongly linked to mode of land ownership.
- In the DRYLANDS project, sand-dams were used for healing soil erosion gullies and improving water storage within the landscape. Farmers' knowledge informed siting of sand-dams in such a way that construction costs were reduced.
- In the CIMMYT case, stakeholders consisting of farmers, extension workers, local government administrators, village cultural and religious leaders, and scientists combined principles from ecological pest management and conservation agriculture to co-created landscape practices that not only increased biodiversity, but also reduced soil erosion, improved water retention in farmer plots, and reduced the incidences of pests and diseases.
- In the CRS-led project in Malawi locally led Watershed Management Committees brought together traditional leaders, district authorities, extension officers, and farmer groups, communities who co-designed and enforced landscape by-laws on grazing, fire and tree protection. They also supported the landscape-wide adoption of soil management practices that improved both crop production and water availability.

Proposition 4. *Monitoring landscape level soil health in order to influence relevant actors requires different or additional indicators from those used at farm level.*

Methods of assessing and monitoring soil health have been a focus of soils research for many years. Current recommended methods aim to measure biological, chemical and physical properties that are relevant to integrated soil health but are not overburdensome to assess at field and farm level [44, 45]. When a landscape approach is used, there are likely to be additional dimensions to assess for three reasons. First, soil health in non-crop fields might best be monitored with different indicators, such as ground cover in grazing land. Second, the impacts of soil management practices on other ecosystem services beyond crop production, such as water quality, may be important. Third, the wider range of stakeholders will have additional interests or 'things they care about' that must be monitored. These reasons can be visualised in the larger set of ecological and social components and their interactions in the framework diagram (Fig. 1). As a specific example, researchers, local government, and farming communities all care about reduction in severe soil erosion and gully size to benefit soil health, but each may prioritize different processes and measurements. There is a danger that the widened interests and set of stakeholders when using landscape approaches will lead to over-burdensome monitoring. Deciding what to monitor and responsibility for doing it will need to be negotiated (Proposition 3).

- o In the CIMMYT case in Zimbabwe, monitoring of livestock numbers and movement was key to understanding and managing soil health because of the role of livestock across the landscape.
- o In DRYLANDS, communities decided to monitor rangeland soil health using the cost-efficient indicators of vegetation cover and type, which describe outcomes they care about, rather than expensive soil organic carbon analyses. These are easy to observe and directly interpretable. In a workshop on assessing systems change within the DRYLANDS project, the indicators that farmers cared to monitor were those that were apparent, visible, and were broader than (or had evolved beyond) those directly linked to biophysical soil health and included social aspects such as women's advancement in leadership and change in gender roles.
- o In the NAFORRI case, mapping of soil erosion hotspots enabled creation of a shared vision and agreement on which practices to try and what to monitor. For example, they measured soil accumulating in erosion control ditches by wheelbarrow load and sediment in river water by a beer glass. This measure of soil loss is an example of an indicator that would not have been assessed if the focus was on plot and farm level rather than landscape level. A landscape perspective of soil health also raised the need to address issues of land degradation in general, including deforestation for fuelwood, insecure tenure and absentee landlords.
- o In the FIPS project, facilitating farmers to measure simple indicators of soil health such as pH across heterogenous landscapes, diverse needs were understood and supported by local (county) government agricultural programs.

Different actors have different perspectives, interests and capabilities for tracking biophysical and social impacts. An established organisation such as an extension service can have durable and widespread means to monitor systems and learn about the challenges and successes of social landscape processes in promoting soil health.

- o In the NAFORRI case, the research agency is coordinating farmer data gathering on indicators including soil retention and stream turbidity, which are of interest to them, easy to measure and show quick impacts. At landscape level, the agency engages with different actors using soil health indicators they show interest in such as absentee landlords' interest in healing gullies, the Uganda National Roads Authority's interest in reducing upland waterflow, the National Environment Management Authority's interest in tree cover and protection of streams, and the district extension officers' interest in attitudes to co-creation.
- o CRS's monitoring, evaluation, accountability, and learning (MEAL) cycle on soil management, that includes household food security and remote-sensed assessment of ground cover, showed the importance of regular feedback to stakeholders at all levels to sustain the effort and adapt respective management activities.
- o The DRYLANDs project has developed a system where farmer groups report back to researchers how actions went, while researchers report back to farmers results from integrating all the information.

Proposition 5. *Facilitating or guiding soil health at landscape level requires different skills, capacities and resources because there are many different interests at stake.*

The framework (Fig. 1) highlights the fact that a landscape approach to soil health involves more stakeholders than farmers alone. Non-farming organisations that have a role can include a water users' group, village authority or conservation organization. These all have their own motivations and interests. There are also norms and traditions governing such things as grazing, access and land use at landscape level. Promoting and supporting improved soil health requires facilitation of some sort, for example by an NGO or government extension staff. The methods used vary – for example, agroecology emphasizes approaches based on co-creation of knowledge and integration of local and scientific knowledge and responsible governance [46]—but any method requires skilled facilitation. When a landscape, rather than farm-level, method is used, the facilitation is necessarily more complex as there are more stakeholders, issues, processes and interests to manage. Hence the facilitation skills and capacities needed will be different and more advanced.

When working at farm level, an agent such as a project officer can announce the opportunity to take part and those farmers interested join in. Individuals can opt out without impact on the remaining participants. At landscape level, all relevant stakeholders have to be engaged. This requires skills in mobilisation, trust-building, negotiation, conflict-resolution, and participatory scenario analysis. Landscape level management of soil health requires skills that enable integration of insights from various biophysical and social and economic disciplines with local knowledge.

- The DRYLANDS project spent much of the first 2 years building trust, raising enthusiasm and helping communities develop a common vision. This involved, for example, working with church leaders as influential members of the community, and required capacity to lobby the local government to prioritise mobilising communities and resources for soil and water conservation. DRYLANDS also used community dialogues and exposure visits to build awareness and relationships. They needed skills in participatory scenario analysis to convince communities that they could achieve land restoration.
- Where NAFORRI works, communities had previous experience of projects that paid for participation in land restoration. It took time and careful negotiation through multi-actor platforms to convince them to engage because of land and soil restoration benefits rather than for cash.
- FIPS facilitated multi-actor knowledge co-creation involving farmers, local government leaders, private agrovet dealers and NGOs for improving soil pH and fertility. This required negotiation, trust building and capacity building skills.
- CAPS conducted multi-stakeholder engagements building from soil health as an entry point towards landscape transformation. It took skills such as trust building and power-relations management.
- To enable and equip facilitators and community groups to design, implement, monitor, and scale restoration effectively, CRS has built a comprehensive toolkit to operationalize landscape management that blends technical rigor with strong social

competencies and facilitation skills. The tools support participatory processes for context-specific planning, monitoring and adaptive management. A skills guide develops the group-work and facilitation competencies needed for landscape-scale action: participatory planning, conflict resolution, collective action, and financial management.

The tools needed to understand problems, envisage alternative futures and solve problems are different when working at landscape level so facilitators need additional capacities to use them.

- o DRYLANDS used participatory mapping of soil health status, back-casting to understand past management history, envisioning and stakeholder mapping against envisaged changes.
- o PKWI used resource and nutrient flow mapping to identify hotspots and underutilised resources

Once cohesiveness is built and collective action is possible there are opportunities and barriers that are beyond farm scale, and facilitators need the skills to navigate these.

- o In the DRYLANDS case, the existing community labour exchange practice known as merry-go-round was mobilised for landscape work on soils, and acted as a platform for knowledge exchange [47].

Proposition 6. *Using landscape level approaches to soil health could change the willingness to invest public resources in soil health because benefits are public.*

The economies of countries in east and southern African are agriculture-based and need public investment in soil health. When the benefits of an investment are private, as happens when individual farmers improve soil health (inner two circles of the framework, Fig. 1), then there is low motivation for commitment of public resources. Successful landscape level approaches lead to social benefits from soil health and related ecosystem services in both farmed and non-farmed areas for diverse stakeholders and hence could be more attractive for investment of public resources. Existing publicly supported landscape processes such as catchment or watershed management programs can provide the framework for soil health investment.

- o In the DRYLANDS case, when community-driven soil erosion control and water conservation yielded multiple benefits such as increased water availability, improved agriculture and agrobiodiversity, the county government became willing to invest in scaling out the approach to other degraded areas. An international NGO also chose to replicate the landscape and community-based approach for restoration of degraded lands.
- o In Bugobero sub-watershed, involving local government officers in a NAFORRI-supported multi-stakeholder platform led to technical and budget support from the district government.

Proposition 7. *Commonly used frameworks for action on soil health need to be updated to accommodate landscape level approaches.*

The frameworks used to conceptualise, plan and monitor action on soil health generally need strengthening to encompass the ideas outlined here. A recent review of soil health framework designs showed that landscapes are included when soil health is part of a broader landscape management approach, rather than through taking a landscape approach to soil health itself [48]. The framework for the African Union plan for 2024–2034 recognises farm and policy levels, but has minimal reference to landscapes [13, 49]. The detailed Action Plan [12] mentions landscapes in only one of 46 Actions, "*Action 3.4.1 Promote integrated soil and water conservation, planning, and management across agricultural sub-sectors and landscapes/ watersheds*". This focuses on promotion without detailed implementation guidance at landscape scales. However, there are plenty of knowledge and ideas to build on. For example, landscape ecology concepts have been used to frame the context specificity of soil health management but the means of taking action at landscape scale have not been developed [50]. There are well developed frameworks for action at landscape scale on related problems, such as restoration or integration with conservation [8–10, 51]. Any of these could be adapted to explicitly focus on soil health.

4 Conclusions

A farm-level approach to soil health management and improvement can be effective and there are many documented cases of positive impact. The concepts, approaches and tools used to improve soil health at farm level will continue to be needed, and to be further researched and developed.

Our broad working hypothesis, stated as Proposition1, is that in contexts like those in east and southern Africa with small farms and interconnected landscapes, a landscape approach, as exemplified by the actions and learning within the cases presented, will enhance farm-level efforts and further improve soil health. However, this does not mean that landscape approaches are inevitable, free of conflict and do not face barriers to success [52]. For example, stakeholders who come together in a landscape sometimes discover conflicts in their aims and interests, or political and economic realities from outside a local region (mining, migration, conflict, export commodity agriculture) that play an outsized role in driving negative landscape outcomes. However we have tried to point out that one key contribution of stakeholder coordination and decision-making around landscapes is to confront, involve, and/or leverage both positive and negative outside factors to improve if not completely resolve the stresses imposed upon local landscapes (especially relevant in propositions 3, 5, and 6 and the way in which local and national government entities are involved in processes that protect and make more efficient use of resources).

Propositions 2 to 6 concern the way context, co-creation, monitoring, facilitation and investment are different at landscape and farm levels and the consequences of this. They address the requirements of taking a landscape approach, including dealing with the complexities that are less prevalent in farm-level approaches. The propositions are also hypotheses. As such they should be debated, refined, tested against evidence and built into a coherent theory.

Proposition 7 is a recommendation for updating available tools and frameworks to support landscape approaches to soil health, with these being founded on the ideas in Propositions 1 to 6. A few broad hypotheses can already be built on the propositions here. For example, we would expect that landscape approaches will show greater positive impacts in areas where there is greater freedom to act in coordination by local stakeholders compared with areas where rigid policy or economic imperatives from outside the landscape are predominant, and also more successful when some key win–win aspects are clear to multiple stakeholders, such as linkages between watershed health, soil health, and nutrition and human compared landscapes in which key stakeholders must negotiate resource conflicts. Building out the success cases here to more counterfactual cases that embody greater barriers, within smallholder systems will help to advance this research agenda.

The results and indications of the case studies presented in this paper reinforce the paper's seven propositions. Together, these cases indicate that when facilitation, evidence and institutions extend beyond the farm, soil health gains become visible, durable and socially owned across landscapes. If the paper's propositions can be institutionalized using described toolsets, embedded in local governance, and aligned with national frameworks, landscape-scale soil health would become both technically sound and socially legitimate at scale.

However, further testing is required, forming a research agenda for systems approaches to soil health management in East and Southern Africa, where our case studies are located, and beyond. Research in diverse contexts will generate the insights needed to refine the propositions and allow them to be used in place-based action on soil health. Together, the propositions point to a change in the common ways in which soil health is conceptualized, action on soil health is organized and research supports the effort.

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All authors wrote and reviewed the manuscript. R.C. drafted Fig. 1. S.N. also initiatated and coordinated the work.

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