Soil Health Challenges in Sub-Saharan Africa: Status and Solutions

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Soil health is an essential foundation for providing the food requirements of a growing population. Technologies for improving soil health are available, but many are only practiced to a limited extent. Partnerships involving governments, the private sector, and research and development initiatives promise to accelerate the packaging of the available data and information; and develop and deliver tailored recommendations that support sustainable soil health management.

Soil health, the capacity of soil to function and provide ecosystem services, is important for sustained food and nutritional security in sub-Saharan Africa (SSA). Agriculture contributes about 23% of the region's GDP and employs about 60% of its population. With Africa's population expected to increase 2.5 times and cereal demand to triple by 2050 (Van Ittersum et al., 2016), soil health is critical. An estimated 65% of the arable land in SSA is degraded, with annual losses of soil nutrients worth approximately US$4 billion. The degradation of the soil's physical, chemical, and biological properties is due to unsustainable land use practices. The main forms of degradation include nutrient depletion, erosion, organic matter loss, biodiversity loss, contamination, acidification, salinization, sodification, waterlogging, compaction, and crusting (**Table 1**; Bado and Bationo, 2018). For example, decline in soil organic carbon (SOC) has been reported from long-term (over 10 years) trials in Kenya, Nigeria, and Togo (Kihara et al., 2020).

Soil health contributes not only to increased crop productivity but also to other ecosystem services, including climate change regulation through greenhouse gas emission controls and C sequestration, water quality provisioning through controlled water and nutrient movements, supporting the functioning of soil organisms and their roles in nutrient cycling, and even cultural services through aesthetic landscapes (Kihara et al., 2020). A healthy soil also supports pest regulation and disease suppression. Soil health is also linked to human nutritional security through improved produce quality. Human nutritional deficiencies have been correlated with poor soils and micronutrients such as iron and zinc. The health and productivity of populations in SSA can be affected by soil health (Joy et al., 2015).

Table 1. Prevalence of selected soil health problems in sub-Saharan Africa.

Degradation form	Status
Soil erosion	77% of Africa is affected by erosion[†]. For example, Malawi loses 30 t ha^{-1} of soil $year^{-1}$ (Omuto and Vargas, 2018).
Nutrient depletion	Almost all countries have a negative soil nutrient balance ranging from -2 to -60 kg N ha^{-1} yr^{-1}, from 0 to -11 kg P ha^{-1} yr^{-1}, and from -2 to -61 kg K ha^{-1} yr^{-1} due to low fertilizer application (average of 12 to 17 kg ha^{-1}) [†].
SOC	Below 1.5% yet declines annually of 2.8 to 13.0 t C ha^{-1} (Namirembe et al., 2020)
Soil biodiversity loss	Soil organisms constitute >25% of the earth's biodiversity. Croplands have lower biodiversity compared to undisturbed or less disturbed soils. Main threats include deforestation, burning of above-ground cover, loss of soil organic carbon, compaction, erosion, landslides, invasive species, and over-grazing (FAO et al. 2020).
Soil acidity	~30% of the SSA have pH < 5.5, mainly in sub-humid areas [†]
Salinization	Over 80 million ha of soils with pH >8.5 commonly in arid and semi-arid areas[†]

[†] from FAO and ITPS, (2015)

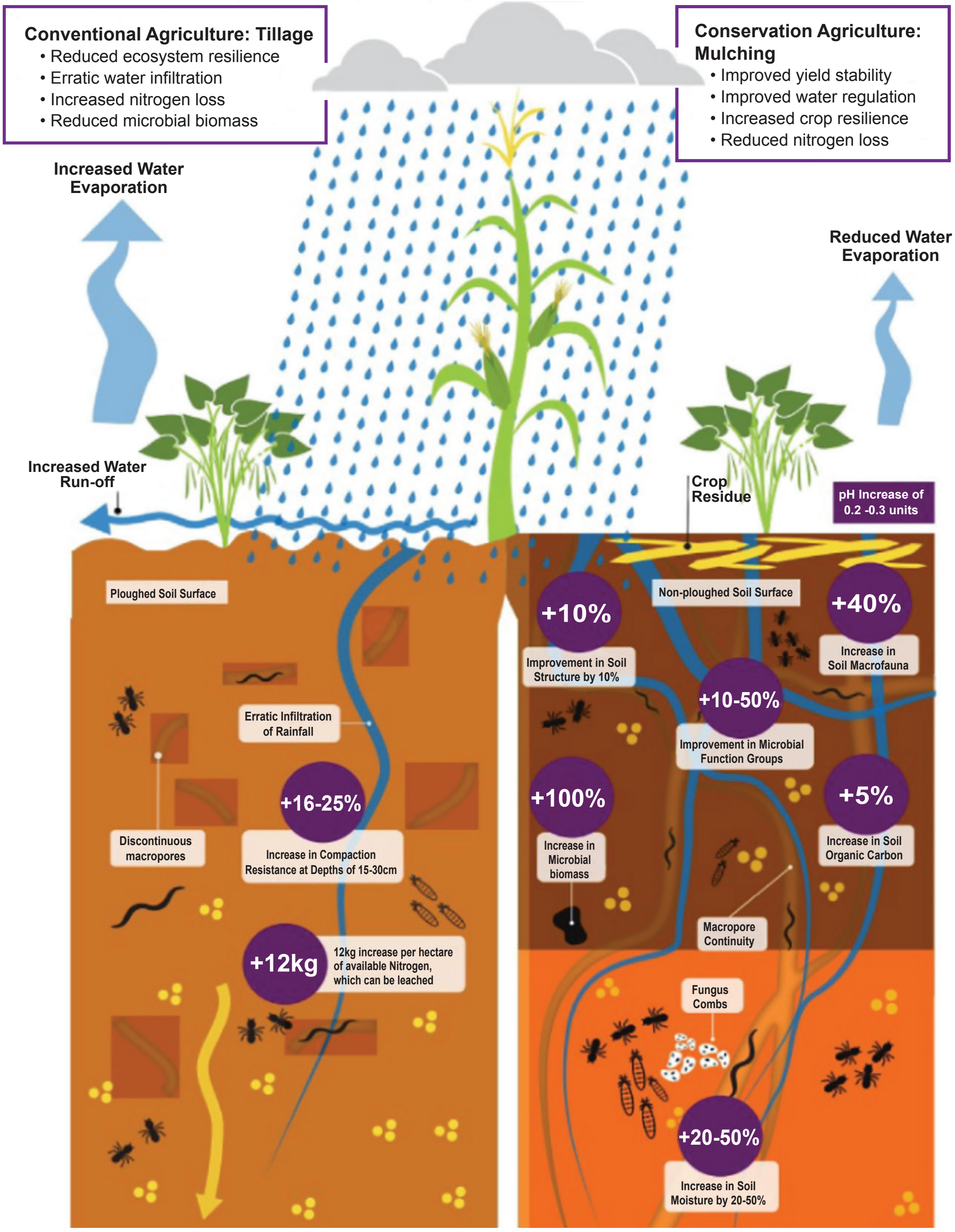

Figure 1. Soil health benefits from CA systems compared to conventional tillage.
Source: Kihara et al. (2020).

The common strategies and practices for enhancing soil health in Africa include conservation agriculture, Integrated Soil Fertility Management (ISFM), agroforestry, crop associations (strip/intercropping, crop rotation), green manure cover crops (GMCC), and pit cultivation technologies. Recently, regenerative agriculture and agroecology approaches have gained interest. Here, the extent of use for the above soil health-promoting strategies is assessed, and some challenges and opportunities discussed.

Managing soil health in sub-Saharan Africa

Conservation agriculture

Conservation agriculture (CA), a practice integrating minimum soil disturbance, permanent soil cover, and crop rotation/associations, is important for soil health and the associated ecosystem services (**Fig. 1**). Scientists have demonstrated more SOC under CA relative to conventional tillage (Sommer et al., 2018; Chivenge et al., 2007), improved soil structure, enhanced soil biodiversity and biological activity (Bolo et al., 2021), soil water infiltration and retention. Despite reduced yields in the initial years of converting to CA in some cases, increased yields are expected in the long term (Kihara et al., 2020; Thierfelder et al., 2013).

Despite evidence of increased CA adoption (**Fig. 2**), hurdles to its adoption include inadequate equipment and machinery to mechanize operations, low supply/availability of crop residues for mulching, and competing needs for residue use as animal feed. Yet, 50% of the farmers are willing to pay for mechanized minimum tillage (Ngoma et al., 2023). Thus, with adequate equipment and machinery there is potential for widespread adoption of CA and participatory CA technology testing can support information diffusion as farmers become agents of change.

Integrated soil fertility management

ISFM consists of four critical components: (i) improved crop varieties; (ii) fertilizer; (iii) organic resources; and (iv) local adaptation, which includes soil and water conservation practices. ISFM is effective for sustainable soil health management and increases

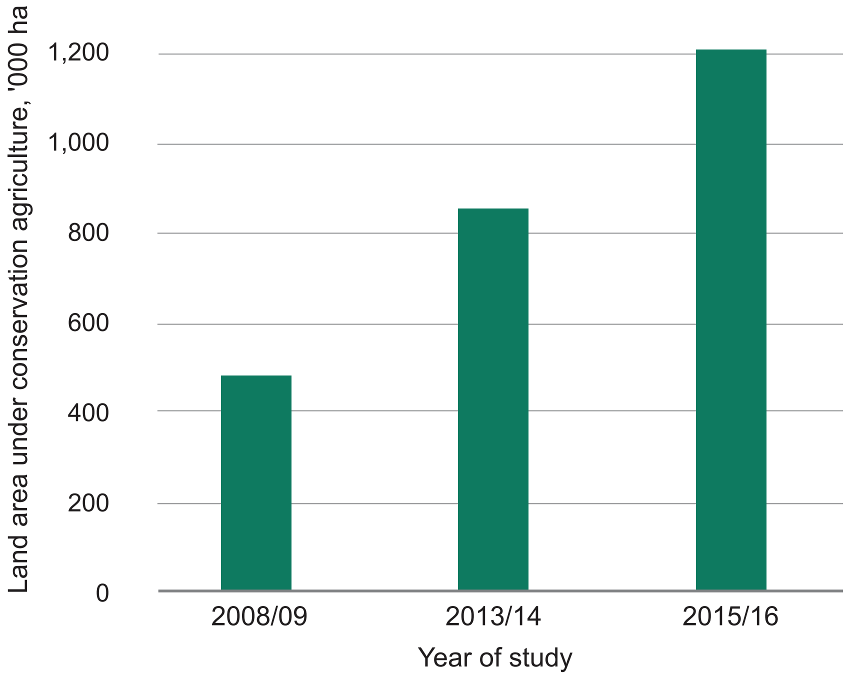

Figure 2. Extent of CA adoption ('000 ha) and expansion in selected countries in Africa (South Africa, Zambia, Kenya, Zimbabwe, Sudan, Mozambique, Tunisia, Morocco, and Lesotho) between 2008 and 2016. Adapted from Kassam et al. (2019).

productivity in smallholder farms reaching up to 300% in some cases, depending on the level of ISFM implementation. But many farmers only have a selected set of ISFM components, even though yields (**Fig. 3**) and economic returns increase with the number of components (Kihara et al., 2022). Employing an increasing number of ISFM components is associated with increased labor costs, but these are often offset by the economic gains. Unlocking limitations that lead farmers to partial ISFM adoption is important.

The practice of ISFM among farmers varies within and across regions. According to Kihara et al. (2022), farmers practiced 1 to 4 ISFM components in sub-humid agroecological zones (AEZs) of Tanzania relative to 0 to 3 components in semi-arid AEZs. There is often high variability in the mix of ISFM components, even within a region, reflecting the complex socioeconomic and biophysical variability that characterizes smallholder farms (Giller et al., 2006; Hörner and Wollni, 2021). Tailored and site-specific management recommendations, and the availability of the inputs required, can support adoption. Sustained scaling out through various strategies is required, especially through national efforts.

Fertilizer use in the ISFM framework can double crop yields. Yet, application rates remain low (Chianu et al., 2012), because of high costs and low returns due to low nutrient use efficiencies under suboptimal recommendations and management conditions. New tailored fertilizer recommendations, for example, in Ethiopia, increased wheat yields (24 to 38%) and profits (**Fig. 4**; Liben et al., 2022). Modest rice

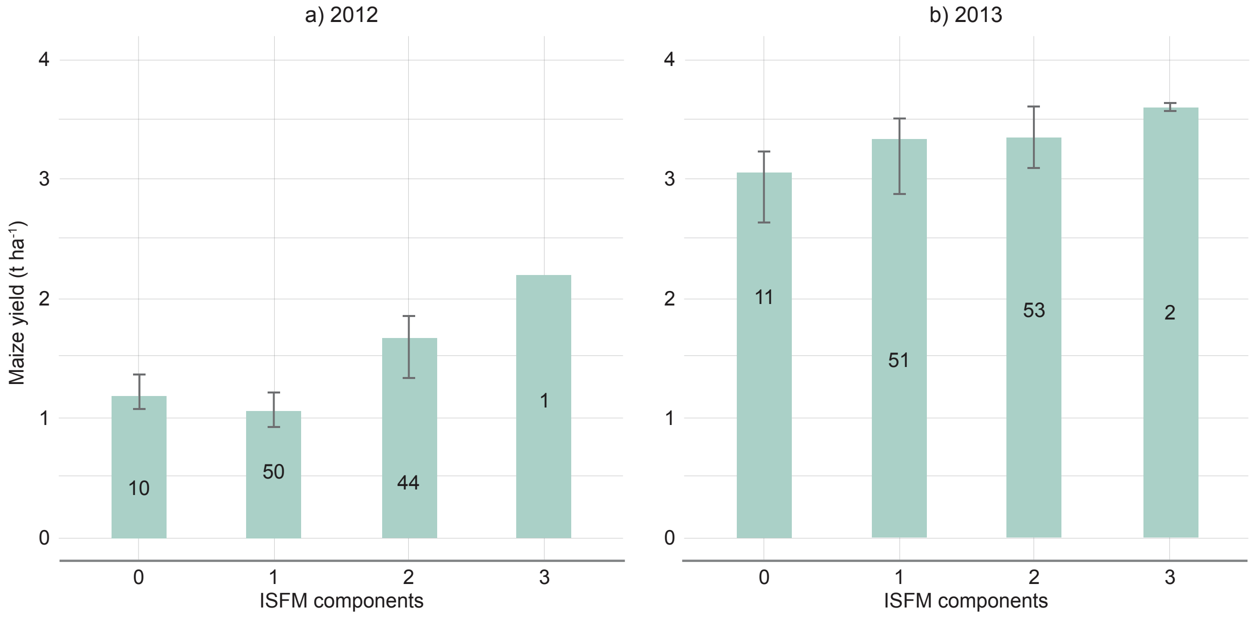

Figure 3. The rate of ISFM component use and yield gains in two separate seasons in 2012 and 2013. The numbers within each column represent the number of fields. Source: Kihara et al. (2022).

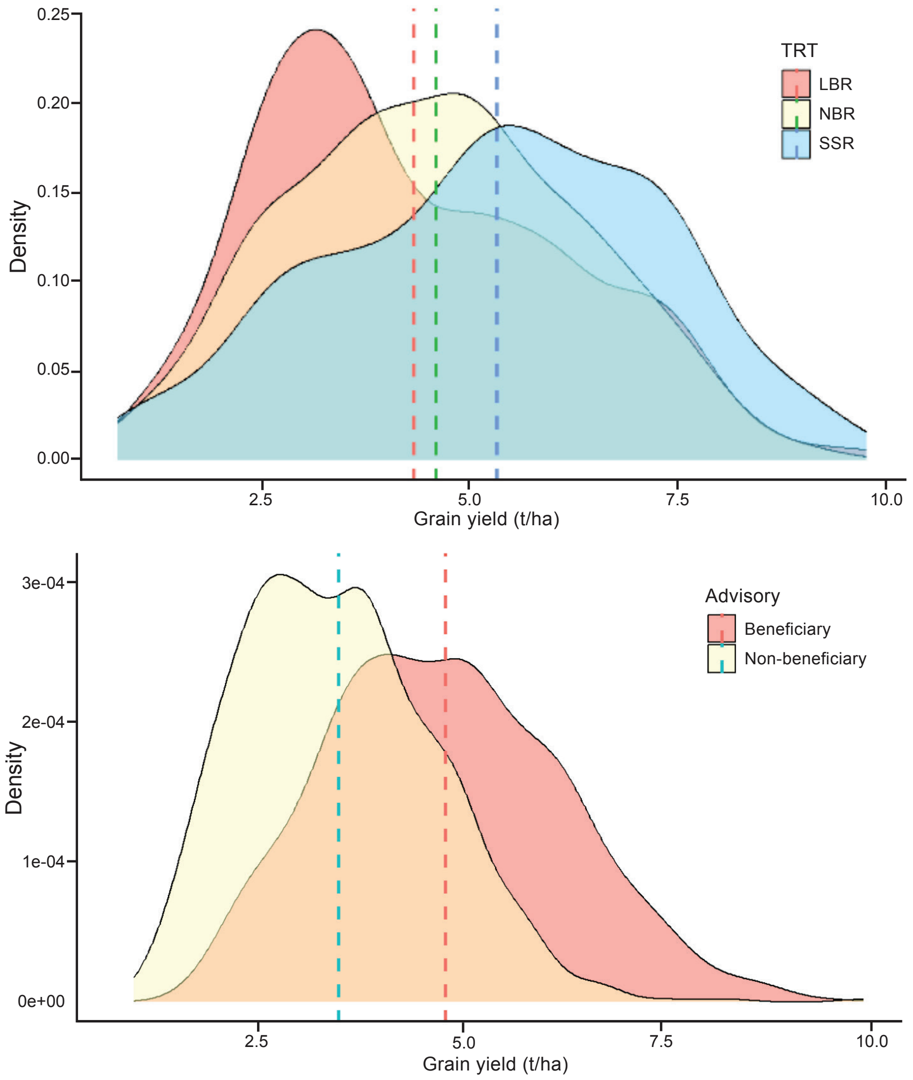

Figure 4. Wheat grain yield observed under local (LBR) and national (NBR) blanket fertilizer recommendations and location-specific rate (SSR) treatments (TRT) across 277 farms in Ethiopia (top) and under new agronomic advisories across 4,000 farms as observed in Ethiopia in 2022 (bottom). The vertical dash lines indicate mean grain yields (Liben et al., 2022). The density values on the y-axis indicate the probability per unit of value shown on the x-axis.

and maize yield increases of 11% and 4%, respectively, were also observed elsewhere compared to blanket recommendations (Chivenge et al., 2022). Upscaling these efforts can result in large changes in the African agricultural landscape. Low rates of fertilizer application in SSA contribute small amounts to greenhouse gases (e.g., N_2O-N emissions from cropland in SSA range from 0.4 to 3.9 kg N_2O-N ha^{-1} year^{-1}; Kihara et al., 2020). However, groundwater contamination and eutrophication of water bodies, linked to uncurbed runoff is widespread. Thus, upscaling of fertilizer recommendations should be accompanied with sustainable land management practices.

Combined application of organic resources and mineral fertilizers is associated with greater nutrient use efficiency and yields than with either organics or mineral fertilizers alone. The manure applied on croplands across Africa can cover just about 10% of croplands (FAOSTAT; **Table 2**). When combined with fertilizers, the area applied with manure can extend.

Crop associations

Intercropping is widespread in SSA and is associated with increased land equivalent ratios relative to monocrops. Cereal-legume intercrops improve soil biophysical and chemical conditions (Chikowo et al., 2020) and fix N (e.g., 53 to 84 kg N ha^{-1}; Mugi-Ngenga et al., 2022). Unfortunately, intercropping systems are often characterized by low yields of the legume intercrops.

Strip cropping innovations increase legume yields, for instance by 101%, 52%, and 15% for groundnuts, soybean, and beans, respectively (Woomer et al., 2004). A triple crop, strip-cropping innovation, Mbili-Mbili, recently developed in Tanzania and now introduced to Malawi and Zimbabwe, improved smallholder food and nutritional security

Table 2. Organic manure use in the main regions of Africa.

Region	Cropland area (Million ha)	Manure (Million t)	Potential area (%)†
Eastern Africa	78	54.8	14.1
Middle Africa	37	16.4	8.9
Northern Africa	50	15.7	6.3
Southern Africa	14	4.9	6.8
Western Africa	102	37.5	7.4
Total	**281**	**129.4**	**9.2**

Source: https://www.fao.org/faostat/en/#data/ESB. †assuming manure to supply 60 kg N ha^{-1} based on an N concentration of 1.25%

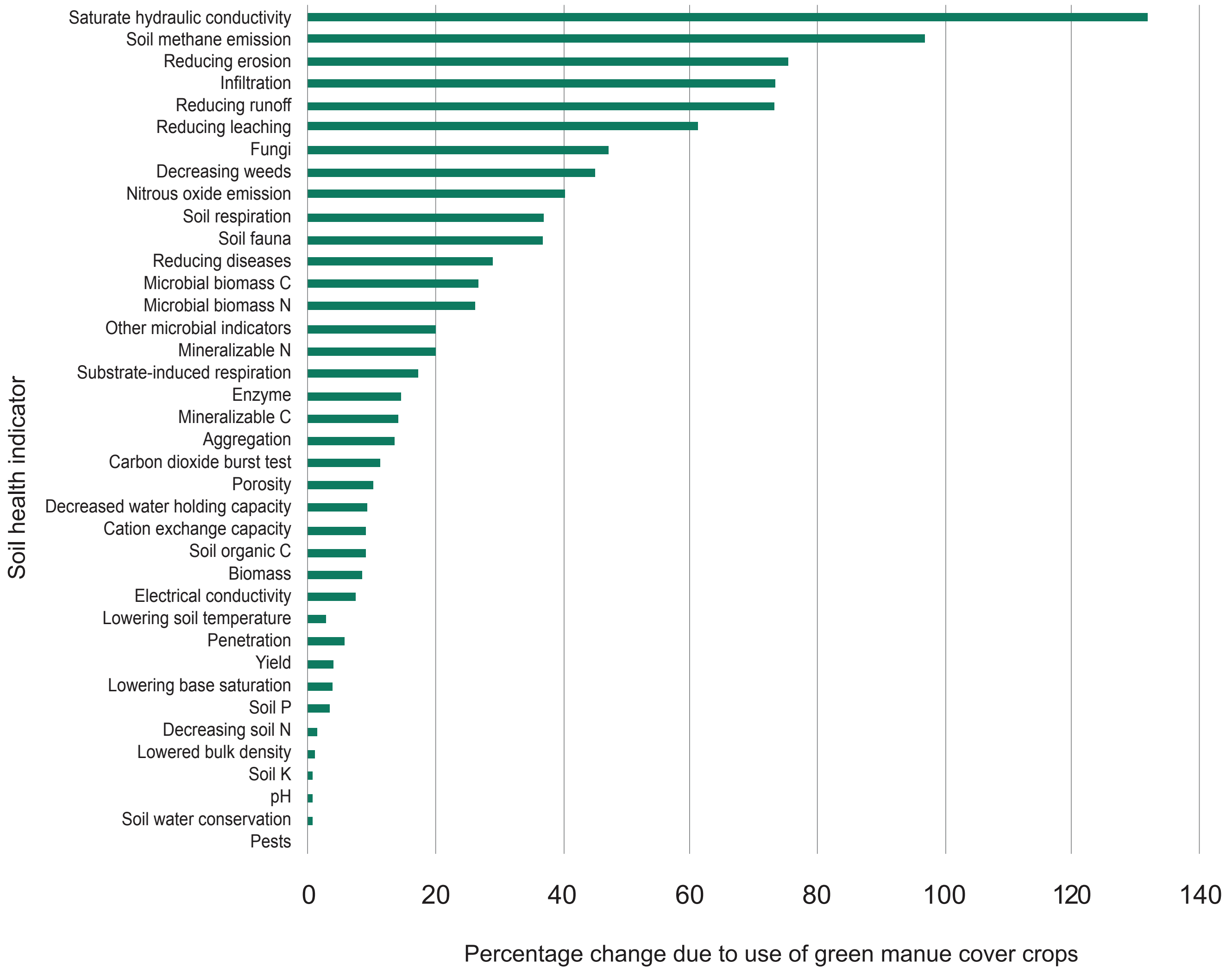

Figure 6. Improvement of soil health as influenced by cover crops relative to no cover crop. Data used in the plot was obtained from Jian et al. (2020).

through increased and seasonally distributed harvests and increased revenues (by $150 ha^{-1} season^{-1}) and their stability (Kinyua et al., 2023). Scaling uptake of these innovations is important to improve soil health and the livelihoods of smallholder farmers.

Legume cover crops provide positive changes of 1 to 133% across various soil health indicators (**Fig. 6**; Jian et al. 2020). Despite the benefits, adoption of cover crops in Africa is still below 50% (Autio et al. 2021), attributed to limited cultivation knowledge, access to seeds, increased labor during cultivation and incorporation, and loss of crop season when rotated with food crops.

Under mixed crop-livestock systems, ley rotation of annual crops with managed perennial/annual grass or grass–legume mixtures (ley) improve crop productivity (5-135%) as well as soil properties (e.g., pH 4%, SOC 12%, pore space 4%, percolation 12%, and infiltration 22%; **Fig. 7**; Wortmann et al., 2021). Alternate ley with annual crop strips of 5-20 m width and rotation cycles of 6-10 yr is recommended (Wortmann et al., 2021). Push-pull is a specific ley cropping technology that integrates N-fixing crops (e.g., Desmodium) and Napier grass strips to increase crop productivity (e.g., 100 to 200% more cereal grain yields in western Kenya; Khan et al., 2011).

Agroecology

Agroecology encompasses all the practices presented here and others (i.e., agroforestry, regenerative agriculture) and is considered as a concept guided by specific principles. In Africa, agroecology can vary greatly across farms with 1 to 5 practices commonly implemented (**Fig. 8**). Approximately 40% of cropland in Africa is under agroforestry, with >45% in humid regions of West Africa, 30% in sub-humid Africa, and <10% in Sahara regions (Zomer et al., 2016; Miller, et

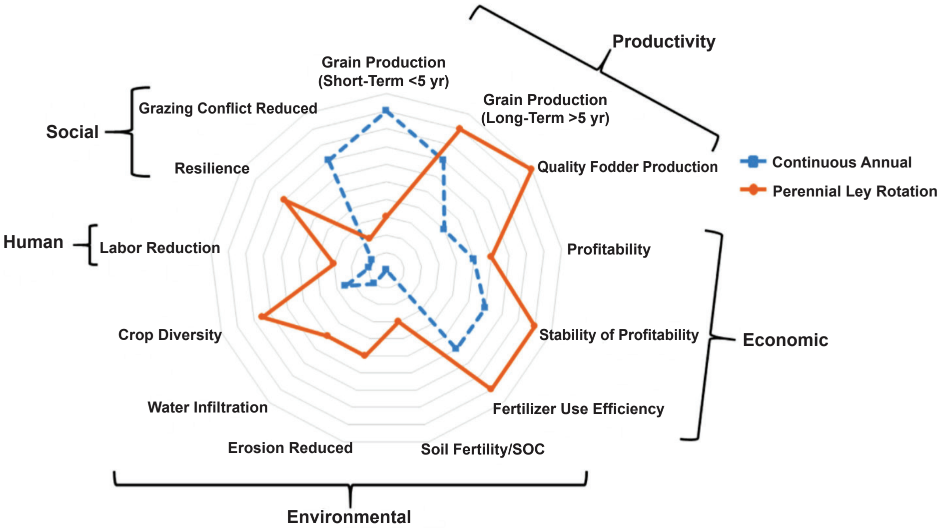

Figure 7. Comparison of continuous annual cropping and ley perennial grass rotated with annual crop (Wortmann et al., 2021).

al., 2017; Kuyah et al., 2021). In Kenya, 56% of the farmers were inadequately informed and 80% required training in regenerative agriculture (Otara et al., 2023). Inadequate knowledge and skills among farmers, and unsupportive policies are barriers to the success of regenerative agriculture. Further scaling of agroecological practices in Africa is important to restore soil health.

Integrated soil fertility and water management

ISFM and in-situ water harvesting in practices involving variable pit cultivation such as Matengo pits (Tanzania), Pfumvudza (Zimbabwe), Mambwe (Zambia), Dagomba (Ghana), Zai pits (Mali and Burkina Faso), Tassa (Niger), and Teras (Sudan) with soil organic matter input into planting pits to build soil organic C (Nyamadzawo et al., 2013), control soil erosion and have the potential to improve soil health. While in specific places the uptake of these practices is appreciable, for example, 50% of smallholder farmers use Matengo in Mbinga district of southern Tanzania (Malekela and Lusiru, 2022), and 52% use Zai Pits in northern Ghana (Danquah et al., 2019), adoption in other places is low and constrained by limited labor and insufficient extension services.

Conclusions

Many soil health-promoting practices are available in SSA, but their adoption remains limited across SSA. Evaluation of the relevance of technologies for specific sites and targeted dissemination is necessary to accelerate adoption and impact. Participatory co-design and implementation processes and farmer training can support farmers to adapt innovations to meet the productivity and soil health targets at the farm and community levels.

Advances in data science and digital technologies offer opportunities for the consolidation and analysis of agronomic data to promote tailored guidelines that are more relevant to the needs and demands of farmers. Research and development institutions, such as the CGIAR through its Excellence in Agronomy Program, are driving research efforts to organize data and support analytics and tool development to generate site and context-specific advisory services. Building broader alliances with public and private sector partners will be necessary to deliver effective advisory services and create an enabling environment for the adoption of innovation for sustainable soil health management. ■

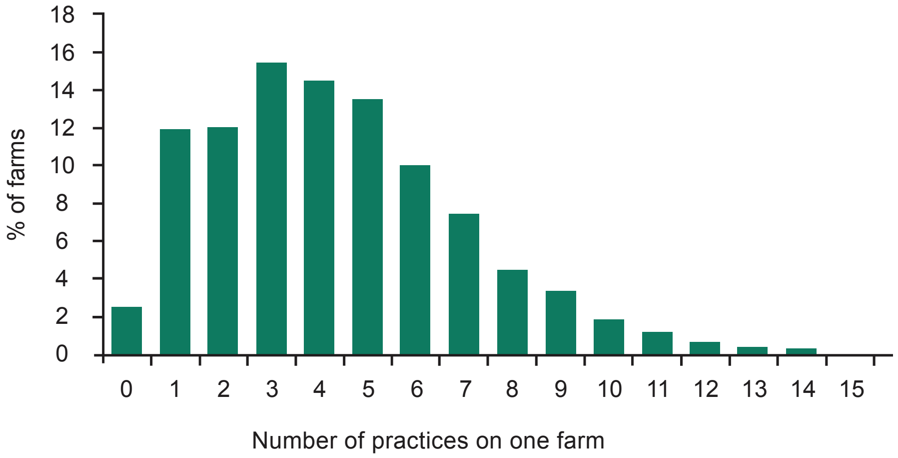

Figure 8. Number of agroecology practices implemented in 5,025 farms across Burkina Faso, Ethiopia, Kenya, Madagascar, Malawi, Senegal, Tanzania, and Tunisia in 2022. Adapted from (Viability Project Team, 2023).

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