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Research Paper

Better Soils for Resilient Agricultural Production

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Abstract: Agriculture plays a pivotal role in improving food security and reducing poverty in Africa, as well as in promoting climate change mitigation and adaptation and general progress on the Sustainable Development Goals (SDGs). In Sub-Saharan Africa (SSA), the agricultural sector employs 70% of the population and is estimated to contribute roughly 15% to GDP. But changing climate conditions and poor agricultural practices lead to soil degradation of up to 65% of agricultural lands in SSA, threatening food security. The "betterSoil" concept is a holistic and systemic approach that stresses the whole, considers essential regional aspects to link economic prosperity and sustainable agricultural practices, and addresses climate change. Its four simple principles – soil management, compost, biochar, and agroforestry – can unlock the potential of soils to restore soil organic matter, to protect soil fertility and biodiversity, and to sequester CO2 for the future build-up of humus in agricultural soils. Better soils can promote economic growth and development, especially in low-income countries hit hardest by climate change. Its four principles support the introduction of climate-positive practices that can be implemented anywhere. To harvest the benefits of large-scale soil improvement, farmers, governments, the African Union, individuals, the private sector, and practitioners must work together to bring theory on better soils into practice.

Keywords:

1. Agriculture
2. Food security
3. Poverty
4. Soil health
5. Sustainability

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1. Introduction

Climate change has significant global economic, societal, and environmental impacts, including extreme weather conditions (floods and droughts), landslides, loss of soil organic matter, soil degradation, and desertification. Studies predict that, without substantial and extensive mitigation actions, negative impacts will dramatically worsen by the end of this century, with the mean temperature rising by 4.1 to 4.8°C (IPCC, 2022, pp. 22 & 23). In the Paris Agreement, governments around the world expressed their goal of keeping the global rise in mean temperature well below +2°C (pursuing efforts to stay below +1.5°C) compared to preindustrial levels (Paris Agreement, 2015). Also signed in 2015, the Sustainable Development Goals (SDGs), in line with their predecessors, the Millennium Development Goals, seek to improve social and economic conditions by reducing hunger and poverty. While also pursuing environmental goals (SDGs 13, 14 and 15), they contain a huge conflict of goals in our current techno-economic system. For a better world in which the SDGs are achieved, a combination of two measures seems to be necessary. First, a fairer distribution of global value creation and income between the poorest 40% and the richest 10%. To fulfill the SDGs solely through such a fairer distribution is possible but not realistic because it would involve a massive cut of wellbeing of today's richest 10%. Hence the second measure of economic growth and wealth creation must also be pursued – through international cooperation that avoids destroying the environment. Probably, this automatically leads to a dematerialization of what we call wealth today. Under current conditions, rising prosperity is associated with increased resource consumption and CO_2 emissions, and with the exploitation of certain low-income groups.

This is why the SDGs and the Paris climate goals are unlikely to be achieved. To fix the issue, we need a paradigm shift toward aligning increasing prosperity with social progress and ecological protection and restoration. In economic terms, such solutions internalize environmental and social externalities of the economy's operation. Especially in the agricultural sector, such efforts are crucial because they promise large gains for most SDGs. The reason is that most people in poor (e.g., SSA) countries work in the agricultural sector. This sector also produces roughly 25% of greenhouse gases while destroying biodiversity and ecosystems. Agriculture is closely connected to the water cycle and nutrient cycles like nitrogen, carbon, and phosphorus – all of which are out of balance. As conditions in this sector improve, women benefit disproportionally as they are overrepresented in agriculture in poor countries. This, in turn, will improve the education of their children. As this article describes, measures to improve the agricultural sector would also lead to improved soil health, with gains for 14 of the 17 SDGs.

Agriculture, forestry, and other land use account for 23% of all global CO_2 equivalent emissions (including CO_2, methane, and N_2O) (IPCC, 2021, p. 188), for 70% of freshwater use (Nhemachena et al., 2020, p. 3), and for 70% of pollution in underground water and aquatic ecosystems (FAO, 2017). Agriculture is also a major cause of deforestation and accelerates soil degradation in agricultural areas, with an annual nutrient loss in soils of about 30 to 60 kg/ha. Over the past 50 years, greenhouse gas (GHG) emissions have doubled in forestry, agriculture, and fisheries and are predicted to increase by up to 30% by 2050 if no effective measures are taken to reduce emissions (Sietz & Van Dijk, 2015, pp. 131 & 139).

At the same time, climate change hurts the agricultural sector and the food production system globally, especially in Africa, and possibly at a faster rate than elsewhere. The climate system affects the survival and reproduction of plants and animals due to rising temperatures, longer dry periods, and more-erratic rainfall. This strongly suggests that climate change endangers resilience and the productivity of agricultural and food systems.

In addition to the increasingly difficult conditions caused by climate change, unsustainable agricultural practices negatively affect soil quality. African agricultural soils are degrading due to erosion, loss of organic carbon, nutrient deficiencies, poor soil structure, and decreased water-holding and transmission capacities. Studies have estimated that in Africa up to 40% of soil is degraded, but more recent studies give higher estimates of up to 65% (Zingore et al., 2015, p. 2; Kihara et al., 2020, pp. 2, 7, & 9).

As a result, gas and nutrient cycles are disturbed and destabilized. Consequently, soil health indicators such as soil fertility, carbon content, biodiversity, water retention capacity, and pollutant degradation decrease. Maintaining and improving soil quality is necessary to meet the needs of future generations in Africa (Nde et al., 2023). This affects 46% of land area and creates costs estimated at US$9.3 billion annually (Nde et al., 2023, p. 76).

As a result of soil degradation, increased desertification, and reduced food production, water quality, natural land resilience and soil fertility decline. Poverty increases and livelihoods are lost, which in turn leads to migration. Soil degradation and desertification are among the most important factors threatening agricultural productivity and resilience, posing a serious threat to nutrition and food security, worldwide and especially in Africa. Under unsustainable agricultural practices, aggravated by climate change, soils cannot adequately fulfill their many ecosystem services to societies. Soil degradation is the primary biophysical barrier to agricultural production in Africa.

Especially bad is the negative impact of soil degradation on smallholder farms in poor regions with low *per capita* food production and low resilience to climate change (Entz et al., 2022, pp. 1 & 2). SSA, whose population will treble by 2100 (Ezeh et al., 2020), already has the greatest poverty concentration (Nde et al., 2023). Of all the people below the global poverty line, 80% live in rural areas, dependent on agriculture for their food security and livelihoods (Nde et al., 2023).

In many countries, the agricultural sector is an economic backbone, especially for poor communities; it generates 15.8% of GDP in SSA (Nde et al., 2023). Adverse agricultural practices have led to disturbances in the soil system causing soil degradation and a loss of US$7.3 billion worth of goods and services in 2015, which is anticipated to increase to US$9.5 billion by 2050. To meet food demand, agricultural production must increase by almost 70% by 2050 (Nde et al., 2023, pp. 76 & 77).

Ultimately, worsening poverty and loss of livelihoods force people to migrate to find alternative sources to support (Dimkpa et al., 2023). For farmers such sources are areas they can cultivate, but such are typically already scarce where they seek refuge. As this introduction has shown, urgent and bold action is necessary. Soil plays a pivotal role in tackling many of the problems touched upon: climate and biodiversity protection as well as promoting the SDGs.

2. Potential solutions

As described above, the current agricultural system strongly contributes to climate change. However, introducing sustainable agriculture practices has tremendous potential to improve living conditions, to maintain a stable climate and healthy ecosystems. All humans depend on agriculture for food, and many depend economically on the (often meagre) incomes they generate from food production. Cooperation to restore agricultural land and its surrounding ecosystems should no longer remain in the niche of development cooperation. It needs to become a focus area for global international cooperation beyond Official Development Assistance, especially across continents. Europe and Africa – neighbors – should lead the way.

To feed the growing human population, especially in SSA, food production must more than double by 2050. Under relatively stable climatic conditions, agriculture in SSA can continue to develop. The detrimental effects of a changing climate and soil degradation can be reversed by implementing innovative and sustainable agricultural practices. The agenda 2063 for “a prosperous Africa based on inclusive growth and sustainable development” tries to invest in modern agriculture for higher agricultural productivity with the Comprehensive African Agricultural Development Program meant to help African nations reduce hunger and poverty.

In this context, the African Union is supporting initiatives to build resilience of African communities by combating land degradation, desertification, biodiversity loss and climate change (Sacande et al., 2021).

By increasing soil fertility toward promoting food quality, water holding capacity to fight desertification, and biodiversity, soils can also be made to act as sinks to capture and bind greenhouse gases. Combined with indigenous knowledge and sustainable land management, innovative agricultural practices can allow farmers to profit from these practices (Dimkpa et al., 2023) – rather than have certain innovative measures imposed on them.

2.1. Better soils are humus-rich soils

Healthy soils are rich in humus. Sturdy, productive, and alive, they contain many living creatures. Healthy, humus-rich soils contain a lot of soil organic matter, dead and alive. As carbon is a composite of all organic matter and living organisms, enriching soils with carbon is vital for soil fertility. To determine soil health and fertility, humus and soil organic matter are good indicators. Approximately 2,500 Gigatons of soil organic carbon (SOC) are bound in humus globally (Beillouin et al., 2023, p. 4; Dunst, 2011)**.** This is more than three times the amount of atmospheric carbon dioxide and five times what is bound in plant biomass. Such humus-rich soils store carbon for hundreds of years – often even longer. Though millions of hectares of valuable soil have been degraded due to improper or excessive use or lost due to rising temperatures and subsequent desertification, this trend can be reversed, and soils be made fertile again. By actively building up humus, our current farming practices can be altered (Lal et al., 2018; IPCC, 2019).

There are benefits of soil humus build-up in different categories, e.g., soil biodiversity, water absorption capacity, nutrient storage capacity, filtering and buffering effects, saturation, carbon sequestration, soil build-up, plant protection, farming for high-quality food, food and the economy as described in Table 1 (Dunst, 2011; Smith et al., 2019; Solaiman et al., 2019; Meléndrez, 2020; Zhao et al., 2023).

Table 1. Categorized benefits of soil humus

Category	Description
Biodiversity	Humus is essential for the richness and diversity of the soil fauna. According to the US National Soil Health Board (van der Putten et al., 2023), applying any soil treatment that kills the soil microorganisms, including the application of minerals and chemicals, results in humus and fertility loss. Humus preserves biodiversity of/in forests, wetlands, and peatlands. By raising yields, higher soil humus content reduces the need for expanding agricultural land with adverse effects on biodiversity. Less land is needed for the same output (productivity increase).
Water absorption capacity	Humus is like a sponge. The ability of humus to absorb water from rainfall and release it when plants need it is 400 m^3/ha per 1% increase in humus This helps plants survive dry seasons and provides a better drainage system on the farm. During heavy rains, humus-rich soil can absorb up to 150 liters of water per hour.
Nutrients storage capacity	Humus greatly enhances the soil's storage capacity for nutrients. At a depth of 30 cm, 1% more humus results in an additional capacity of 2,500 kg/ha of nitrogen in the soil (Tsai & Chang, 2019)

Table 1. (Continued)

Category	Description
Filtering and buffering effect	High filtering and buffering effects of humus include filtering and purifying rainwater and groundwater. Humus provides a porous, soft, and aerobic space, like the structure of a sponge, which makes the soil better able to capture pollutants and pathogens. When humus builds up and carbon sequestration increases in the soil, the soil particles are coated with organic matter, absorb more pathogens, and substantially prevent them from being moved away by infiltration and runoff. This helps suppress the pervasion of soil-borne crop diseases.
Saturation	The saturation of the humic structure of the soil with water and nutrients allows additional rainwater to flow through to form groundwater. On dry and compressed soils with low humus content, water cannot penetrate and runs off, thus increasing the danger of flooding and topsoil erosion. Groundwater to support the ecosystem during dry periods is not formed.
Carbon sequestration	Humus formation has high carbon sequestration potential. Humus can bind 2-25 tons CO_2/ha/yr. Adding humus to the soil (humus build-up) by fertilization with 8 tons/ha/yr of compost led to an increase of 115 kg carbon/ha/yr. Applying compost at higher rates of 14 and 20 tons/ha/yr caused accumulation of carbon at rates of 558 and 1,021 kg/ha/yr, respectively. Accordingly, several soil functions, as well as overall soil health, were improved by soil carbon sequestration (Erhart et al., 2016).
Soil build-up	Humus prevents erosion by holding soil aggregates together, increasing organic matter, maintaining soil pH, and protecting soil from extreme climate.
Plant protection	Plants are healthier and more productive in soils that contain humus. By enabling plant roots, soil microbes, and soil structure to interact with one another, deeper root growth is possible, and humus increases plant health and promotes nutritional balance. Additionally, it holds oxygen, which is necessary for root development and supports the growth of root structures.
Farming for high-quality food	Grain yield (e.g., maize) can increase by 2.1% per year due to an increase in the soil organic carbon (SOC) pool by 0.5 tons of carbon/ha/yr. In Africa, an increase in the SOC pool by up to 1 ton/ha/yr can potentially increase food production by 9-12 million tons (Lal, 2006, p. 203). In Kenya, soil carbon conservation and farming through sustainable agricultural production can increase grain yield by 50 kg/ha for beans and 243 kg/ha for maize (Kapkiyai et al., 1999). In Western Nigeria, the SOC content in the topsoil layer (0-10 cm) was studied. For each 1% rise in SOC, an increase in yield was observed of 2.9 tons/ha for maize and 0.23 tons/ha for cowpea (Lal, 1981).
Economy	By contributing to safer and cheaper production in the medium and long term, humus leads to significant cost and effort reductions in protecting plants and soils from the adverse and devastating effects of climate change. Soils with humus mitigate climate change and help adapt to is by increasing resilience.

2.2. Four principles for increasing humus content and overall soil health

Humus provides multiple ecosystem services as benefits to humans and significantly paves the way for closing carbon and nitrogen cycles. Thus, humus has the potential to contribute substantially to climate change adaptation and mitigation (Lal et al., 2015).

> Programs to eradicate poverty and ensure food security can benefit from applying measures that promote neutrality of land degradation (including avoiding, reducing, and reversing land degradation) in rangelands, croplands, and forests, which contribute to combating desertification while mitigating and adapting to climate change within the framework of sustainable development (IPCC, 2019, p. 20).

The suggested 'measures' and agricultural practices mostly involve building up humus in the soil. In what follows, these practices will be introduced in the form of four principles to improve soils.

A) Compost

Compost is produced by the aerobic decomposition of organic matter. Applied on soil, compost has significant impacts on the improvement of its physicochemical properties. Various raw materials can be used as feedstocks to produce compost, such as organic waste from farms, manure in general, green manure legumes, and kitchen waste. Generally speaking, compost increases soil nutrient content and enriches soils with a wide diversity of microorganisms and fungi. This contributes to higher yield and enhances soil health. At the same time, farmers combine waste disposal to increase their own health with a cost-effective opportunity to increase their soil's health.

Applying compost is highly recommended as a common practice, especially in areas where SOC is low, and soil nutrients are subjected to leaching and gaseous losses. In low-input farming system such as SSA, compost can add more nutrients to the soil and increase the yields of the main crops (Frimpong et al., 2021, p. 2; Maselesele et al., 2021, p. 1). The continuous reduction in soil fertility in SSA causes a severe deficiency of phosphorus (P) in the soil, one of the main factors that constrain, e.g., maize production in Kenya. In this case, Orandi et al. (2021, pp. 332 & 334) observed an increase of up to 13.5% in maize height and a significantly yield increase of about 55.9% by applying phosphorus-fortified compost using rock phosphate. However, to avoid excessive usage of mineral P fertilizers, Gwandu et al. (2023, pp. 10 & 11) observed that co-amendment levels of 5% and 10% to compost and residual aluminum sulphate water treatment resulted in a reduction of P fertilizer requirements to 60-70% and 30-60%, respectively. This also helped improve crop yields and rebuild soil health in sandy soils of urban agriculture in South Africa. Here, Mohale et al. (2023, pp. 5, 6, 9, 10, & 11) conducted another study where they recommend applying at least 10-15 tons/ha of Eucalyptus wood-based compost to significantly raise the value of soil physicochemical properties governing decomposition of soil organic matter. This includes pH levels, electrical conductivity, organic and active carbon, mineralized nitrogen, plant available nutrients, bulk density, and soil texture.

In West Africa, Cardinael et al. (2022, p. 2) showed that combining compost and mineral nitrogen (N) fertilizer can increase the yield of maize from 5 to 6 tons/ha/yr. Every year, they observed a yield increase of 1 ton/ha, with SOC loss more than halved from -0.62 (without compost) to -0.27 (with compost) tons of carbon/ha/yr).This means for every ton of maize yield increase roughly one extra ton of CO_2 was stored in the soil.

In Cameroon, Tchida et al. (2022, p. 1) showed that enriching compost with biochar and mycorrhiza improved soil texture from sandy to clay-loam and soil pH of the soil from a very acidic to an alkaline situation. To support this, another study conducted by Tovihoudji et al. (2022, pp. 1 & 5) in northern Benin showed that enriching compost with 15% biochar resulted in higher (+86%) cotton seed production and significantly improved growth and yield of cotton. Overall, enriched compost combinations accelerate the activity of soil fauna and increase soil nutrients and water content, resulting in a smooth establishment of vegetation on degraded and degradation-prone soils of SSA (Tchida et al., 2022, pp. 14 & 16).

Furthermore, a study by Hawkins et al. (2023) has illustrated the massive potential of mycorrhizal fungi for storing carbon below ground. After reviewing more than 194 data sets and peer reviewed papers, the researchers estimated that plants pass between 1% and 13% of their carbon to mycorrhizal fungi. This is more than 13 billion metric tons of CO_2 and equivalent to approximately 36% of annual global fossil fuel emissions. The estimates were reached using conservative methods of quantifying carbon, so the mycorrhizal fungi may actually be storing much more carbon. In addition to the carbon sequestration capabilities of fungi, the immense benefits that fungi bestow on above- and below-ground ecosystems make it imperative that fungi and indeed fungal biodiversity be included in policies and practices aiming to support soil systems on which life depends. When farmers compost their organic agricultural waste, they breed fungi in their compost. Applied on their cultivated area they can unlock the power of compost with nutrients, microorganisms, and fungi.

B) Biochar

Biochar is a carbon-rich material produced from biomass. The organic input material is burned with very little oxygen. In SSA, biochar is slowly but increasingly being used as soil amendment and biofertilizer. Studies have shown that there is great potential and opportunities for biochar applications as soil amendment that also provides other environmental uses. Studies in Zimbabwe estimate that the country has biochar feedstocks of approximately 9.9 Mt/yr, derived mainly from manure (88%) and firewood (10%) and can yield 3.5 Mt/yr of biochar (Gwenzi et al., 2015). In Africa, biofertilization using biochar is mainly aimed at improving soil health and properties to enhance crop yields. Statistical meta-analysis studies using field trials of crop yield data in SSA show that biochar increases cereal grain yields by 0.18 to 1.00 tons/ha/yr (Dickinson et al., 2015). In their long-term study in subhumid regions in Kenya, Kätterer et al. (2019) showed over ten years that adding biochar to maize-soybean rotations increased yields and soil fertility. Specifically, this study showed the effect of biochar fertilization independently from other fertilization, seasons, and locations: seasonal yield increased on average by 1.2 tons/ha for maize and 0.4 tons/ha for soybeans (Sundberg et al., 2020). A similar study in Kenya using different biochar application rates (1, 5, and 10 tons/ha) showed that the maize grain yield (dry matter) on average increased by 1.0, 2.6, and 4.0 tons/ha, respectively, compared to control plots without biochar treatment (Kätterer et al., 2022, pp. 18 & 21).

Furthermore, these studies also demonstrated that incorporating biochar in small-holder farms in agricultural landscapes in Kenya significantly reduced their greenhouse gas emissions. In Western Zambia, characterized by acidic sandy arenosols, biochar fertilization increased maize yield by 350-450% (Obia et al., 2019). Under typical semi-arid conditions in South Africa, crop residue management in croplands resulted in cumulative carbon input ranging from 10.65 to 12.16 tons/ha, significantly enhancing grain yields (Nyambo et al., 2020, pp. 5 & 10). Furthermore, in Tamale, Ghana, farmers almost doubled (+93%) their lettuce yields by producing biochar on-site and including its application to their conventional agricultural practices (Steiner et al., 2018). The higher crop yields due to biochar fertilization, especially when incorporated with green manure (e.g., legumes), can be linked to increased N availability. A study in Benin showed that 156% more nitrogen was available on plots treated with biochar and legume green manure than on control plots (Partey et al., 2016).

More colloquially speaking, biochar is porous and has a large surface area. These characteristics enable biochar to act like a store for water, nutrients, microorganisms, and fungi, enabling them to survive under harsh conditions like droughts and heavy rainfalls. This is especially true of biochar applications in combination with compost: nutrients, microorganisms, fungi, and water are bound in a stable way to the structures biochar provides. As a result, plants can access needed input and interact with soil biology to the degree and at the time necessary.

C) Soil management

Soil management (SM) is a set of appropriate agricultural practices to protect soil performance, to make soils more fertile, to mitigate climate change, and to increase adaptation to climate extremes. This includes techniques and technologies promoting minimum soil disturbance, i.e., no or low tillage, maximum soil cover by cover crops, mulching and crop residues, crop diversification by intercropping (e.g., peanut-maize-beans), soil buffering by afforestation, or covering the soil with shrubs, grasses, and canopy of plants or trees and preventing soil fallow by crop rotation (e.g., beans-vegetables-maize) (Dunst, 2011; Ahmed et al., 2019, p. 66).

Low soil fertility and soil degradation are key results of poor and intensified farming practices and of recurrent, prolonged drought in SSA. Subsequently, such soils are characterized by a deficiency of essential nutrients. Adopting SM practices is vital for avoiding the loss of major agricultural products due to soil loss constraints. SM practices not only improve the physico-chemical properties of soil. With their pronounced evident role for biological indices such as stimulating soil fauna, they also play an important role for soil carbon sequestration and aggregation, nutrient cycles, and water use efficiency. Ultimately, the implementation of proper SM practices enhances soil health, maximizes crop yield, and ensures safety in food production. Proper SM practices pave the way toward achieving sustainability in agriculture (Ahmed et al., 2019, pp. 59, 61, & 65; Ayuke et al., 2019, pp. 1, 2, 7, & 10; Tufa et al., 2023, pp. 17 & 24).

The soil fauna is an important soil biological index and a suitable sustainability bioindicator of conservation measures to combat soil degradation in SSA (Danra et al., 2021, pp. 161, 163, & 175). It was shown that the development (e.g., higher abundance levels) of soil fauna indicates the efficiency of SM practices in restoring degraded soils and maintaining soil fertility. In this regard, Nde et al. (2023, p. 75) substituted mineral NPK (Nitrogen, Phosphorus, Potassium) fertilizers with mulches that can be prepared in simple ways and are easily accessible by farmers. As a result, the soil fauna was promoted with a positive impact on the soil structure and the microclimate. With dead organic matter added by mulching, 26% higher water content was documented in the soil. Regarding minimum soil disturbance, Thierfelder et al. (2022, pp. 166, 169, & 175) proposed no-tillage plus crop residue retention as a solution for the sustainable development of soil carbon and suitable investment in soil organic matter in maize fields in Zimbabwe. In their study, the relationship between soil physicochemical properties and maize productivity varied by soil type. They suggest that especially sandy soils should not be tilled. Ma et al. (2022, pp. 2145, 2150, & 2156) found that in vast areas of Kenya and Ethiopia, an integration of SM practices such as no-tillage, residue and manure application as well as cover crops can increase SOC levels (11%), carbon storage (4%), maize crop yield (22%) and overall crop production (18%). These measures promote food security and more sustainable agricultural production in the long term. As a result, SM practices can eventually contribute to enhancing soil health with a perspective on climate change mitigation and, subsequently, boost agricultural productivity in SSA (Nde et al., 2023, pp. 77, 86, 89, & 91).

Depending on the regional conditions concerning soil type, climate, precipitation, farming system etc., soil management to increase humus content needs to be different. It is helpful to include measures applying compost and biochar in SM strategies as well as the next principle, agroforestry.

D) Agroforestry

Agroforestry has a long history, not only in SSA. As sustainability becomes increasingly important, agroforestry has moved into focus again because it combines the ecological, socioeconomic, and environmental benefits of both forestry and agriculture (Bucagu et al., 2013). Agroforestry systems consist of rotational cultivation of trees or shrubs with agricultural crops. As mentioned above, many people living in SSA directly depend on the agricultural sector and struggle with the adverse impacts of climate change. Especially among smallholder farmers, agroforestry systems have great potential to enhance crop yields and to promote overall productivity toward meeting the ever-growing demand of SSA's population for grain food and moving to a climate-adaptive farming system (Kuyah et al., 2019; Muthee et al., 2022).

A good example is the leguminous *Faidherbia albida*, commonly intercropped with millet and groundnuts in SSA, which via leaf fall deposits on food crops substantial amounts of organic matter that acts like a fertilizer. Dense stands of *F. albida* (e.g., 50 large trees per ha) have been reported to produce a significant amount of green manure equivalent to almost 50 tons/ha/yr of manure. Studies on this combination of millet grown with *F. albida* in agroforestry systems increased grain and protein yields by a factor of 2.5 and 3.4, respectively (Mokgolodi et al., 2011).

Agroforestry systems and improved fallows (ranging from 1-5 years) have enhanced SOC and sequestered on average 2.2 (minimum 0.7 and maximum 8.3) tons of carbon/ha/yr (Partey et al., 2017; Kihara et al., 2020, pp. 1 & 7). According to Reppin et al. (2020, p. 203, 204, & 214), in an agroforestry system, total farm carbon stock is determined by the type of agroforestry practice, farm size, tree density, and the average size of trees on the farm. The dominant support services (60%) generated by agroforestry in SSA are soil formation and soil fertility (Muthee et al., 2022).

In a meta-analysis study by Muchane et al. (2020, pp 1, 12 & 20), it was estimated that the agroforestry system in humid and subhumid tropics of SSA could reduce soil erosion by 50% and increase SOC, available N, available P, and soil pH by 40%, 46%, 11%, and 2%, respectively, compared to monoculture cropping. Moreover, trees provide shade that reduces evaporation of water contained in soils and protects crops and soil biology from the negative effects of strong sunshine.

Therefore, agroforestry can significantly contribute to an agroecological transition towards high crop productivity, low crop failure, food security and restoration of degraded agroecosystems based on increasing SOC as well as to climate change adaptation and mitigation in SSA (Muchane et al., 2020; Muthee et al., 2022).

3. Call to action – Joint efforts can bring the transition

Establishing large-scale superior farming methods is necessary to accomplish the SDGs, especially to increase yield for a growing population and create better living conditions for farmers, but also to reduce GHG emissions, fight desertification and protect biodiversity. The combined action of different stakeholders in a joint effort is necessary to achieve this. Hence, the authors want to encourage organizations, private sector actors, practitioners, politicians, and individuals to add their pieces to the transition puzzle.

3.1. Calling on practitioners/farmers in the agricultural sector

BetterSoil farming methods based on the four principles outlined above must receive greater international attention in practice. In the end, it is the farmers that need to implement them. Although the agricultural sector is responsible for approximately one quarter of global GHG emissions, farmers cannot be blamed for the whole agricultural system. Often, they suffer from exploitative conditions and injustice. However, if conditions are set up correctly, farmers can build the bridge between different academic and political silos and become protectors of biodiversity and the climate, while also providing high-quality food for societies. For soil improvement, it is necessary to close the carbon and nitrogen cycle in the soil. Because the primary cause of climate change is imbalance in open geochemical cycles, soils as the major carbon reservoir on land play a big role. Here, it is important that farmers working towards these goals be rewarded.

Mid- to long-term, the benefits significantly outweigh the costs. But, depending on the specific situation, short-term financial or practical support is often needed for the transition from the current farming system to one furthering soil humus formation. Finally, implementing betterSoil practices strengthens the resilience of farms against the adverse effects of climate change. Such practices are thus an investment in soils, which are the capital of farmers and of our societies.

From the participation of Ethiopia, Kenya, and Tanzania in implementing soil management practices we have evidence for comparing farmers' experience and knowledge about soil health with scientific measures. A study supports including farmers as effective monitoring participants in regard to soil health benefits to increase the knowledge exchange between farmers and scientists promoting practices for soil improvement. This is a good contribution of farmers in evaluating the schemes for soil restoration in East Africa (Entz et al., 2022, pp. 1 & 13).

3.2. Calling on the private sector (industry, entrepreneurs, and business leaders)

Increasingly, the global economy is facing multiple crises simultaneously. For years, countries in dry areas have been experiencing the effects of a changing climate. Recently, environmental extremes like water scarcity, drought, and wildfires during dry periods, as well as heavy rainfalls, have also been experienced by high-income countries in Europe and North America. For companies, these effects lead to increased operational costs, destroyed capital, higher general risk, and distorted business models through supply chain disruptions. A stable economy needs a stable environment and stable societies. For the decades to come, this means that resilience of the economic system needs to be improved.

Although costs caused by adverse climatic effects and biodiversity loss are difficult to quantify, prospects are clear: the higher the temperature rises, the bigger the problems become. Hence, most companies have an economic self-interest to work on climate and biodiversity protection. Companies with (global) supply chains in the agricultural sector already feel those effects. Many of them start acting already, but the pace should increase. Companies outside the agricultural sector also need stable economic and social conditions. Consequently, they too have reason to support better soil practices toward promoting the SDGs and protecting the climate and biodiversity so as to reduce detrimental instability in the overall system.

People reflexively refer to governments to work on solutions when raising issues like poverty, climate change, or biodiversity. But can they address these issues? Do they have the resources? Not fully. Currently, the private sector has five to seven times more wealth and capital than states (Alvaredo et al., 2018). Worldwide government spending on sustainability issues is on the order of hundreds of billions of dollars. Estimates show, however, that effective solutions require trillions rather than billions. The longer we wait, the higher the costs will be.

When farmers want to change their system to a targeted humus economy to close the carbon and nitrogen cycles, they need financial support at least for some years in the transition. Organizations like betterSoil likewise need financial support to help in this transition. Through voluntary action, companies can provide this support. This helps them, too, because it works towards a stable economy and an overall decrease in economic inefficiency. Contributing to the SDGs and ensuring climate and biodiversity protection is becoming increasingly important when considering the operating license. Employees want to know whether they are working for a company that cares and uses its influence for a better world. Consumers want to buy products from companies living up to high values. Legislation recently also increased pressure on companies to support sustainability. The European Corporate Sustainability Reporting Directive requires companies to report about different sustainability indicators.

May companies live up to their great responsibilities commensurate to their capabilities!

3.3. Calling on governments

Each state has its own expertise and responsibility. To encourage more policy makers and practitioners to protect the climate and to promote economic development, states should implement betterSoil practices in their countries and encourage them through their policies. When adopting betterSoil practices, they should give small-scale farmers economic and political support toward making their food production more resilient to climate change and economic disturbances.

In SSA, several projects and initiatives aim to promote and integrate sustainable agricultural land management practices among small-holder farmers. For example, Vi Agroforestry's Kenya Agricultural Carbon Project trains approximately 30,000 small-holder farmers (small farm size area <2.5 ha) in Western Kenya in agroforestry, cover cropping, composting, and organic manure management, to improve soil health and C sequestration in croplands, and ultimately to improve crop yields and economic returns (Nyberg et al., 2020). Such initiatives also enhance small-holder farmers' resilience to climate variability and change.

Governments can provide the right framework for effectively applying the betterSoil principles. Collaborating with scientists and practitioners, they can shape regulatory incentives, e.g., by subsidizing beneficial measures and penalizing negative externalities like GHG emissions. Across continents and income levels, governments should act together in co-financing betterSoil practices. Oftentimes for example costs for carbon removals and avoidance strategies are much higher in high-income countries than in low-income countries. Furthermore, implemented in the latter, climate protection measures can create all the mentioned co-benefits regarding the SDGs, thus creating a win-win situation.

May states collaborate in providing mutually beneficial incentives for efficient (financial) resource allocation!

3.4. Calling on the African Union

The United Nations (UN) has declared the years 2021-2030 as the UN Decade on Ecosystem Restoration. With this initiative, global restoration efforts should be promoted to reach the necessary scale. Especially for Africa, this decade provides enormous restoration opportunities because the continent has a large need and substantial potential for restoration. For the UN Decade on Ecosystem Restoration to be successful, it must succeed in Africa. Prompt identification of opportunities is important to ensure proper planning and successful implementation of restoration initiatives in Africa (Nsikani et al., 2023). To restore degraded African soils and increase their fertility, to bind atmospheric CO_2 in the soil and directly contribute to climate resilience, the African Union (AU) should place greater emphasis on betterSoil practices and humus enhancement in its agricultural policies. The betterSoil principles can also support the Comprehensive African Agricultural Development Program to develop resilient agriculture in African nations. This Program and the African Agenda 2063, "The Africa we Want," provide a good foundation for increased action on healthy soils.

Farmers and actors involved in food production should be rewarded for actions that help close nitrogen and carbon cycles, which means avoiding, reducing, and removing atmospheric GHGs to benefit the climate (Nsikani et al., 2023). Moreover, the AU should also demonstrate greater commitment to support African initiatives, such as AFR100 (the African Forest Landscape Restoration Initiative), to restore an estimated 100 million hectares of land by 2030. However, for such pan-African initiatives to be successful and to contribute to the 'Africa, we Want', the AU and its member states must be the main partners for a successful mobilization of financial and technical resources as the foundation for country-specific implementation strategies. Herein, the coordination at the state level in Africa and multilateral cooperation with, e.g., the European Union, are of utmost importance. This may include but is not limited to biodiversity conservation, forest and ecosystem rehabilitation and restoration, rangeland management, and climate-positive as well as regenerative agricultural practices. Ultimately, these initiatives will galvanize 'sustainable solutions for land restoration and drought resilience, with a strong focus on future-proofing land use,' (FAO and UNCCD, 2022) as envisaged by UNCCD's 197 Parties at COP15. Connecting restoration efforts with the Nationally Determined Contributions that states have submitted pursuant to the Paris Agreement can increase the efficiency of envisaged measures.

May the AU continue to raise its pan-African voice to increase the efficiency of multilateral cooperation, which is needed more than ever.

3.5. Calling on individuals all around the world

Joining initiatives to improve soil health is highly recommended. Recruit at least two people from your family, friends, or colleagues and inspire actors from the private and political sectors to become more engaged in global climate protection and sustainable development through betterSoil practices. This topic needs more awareness of societies, their governments, and their decision-makers. Acting as a betterSoil ambassador, promoting the benefits of betterSoil solutions can create this awareness. Give financial support to farmers and projects that use betterSoil farming methods locally and worldwide. Encourage your political representative to work on soil improvement policies. Encourage your employer to set up a strategy aligned with the values of a responsible business benefitting societies and not only increasing shareholder value – yes, working on soils can bring these components together, especially in cases where business models directly depend on sustainable supply chains. Become a net climate-neutral individual and become involved in promoting the topic, as your contribution is crucial for advancing the global puzzle towards a better world.

Individuals, raise your voices and connect to promote grassroots support for soil improvement.

4. Conclusion and outlook

The science is clear: sustainable farming practices enhancing humus in soils – applying betterSoil principles – have enormous potential to protect the climate and biodiversity and to support the SDGs (Figure 1). Therefore, this paper seeks to attract the attention of all stakeholders to promote the application of betterSoil farming practices. This also promotes actions at the AU and global levels through ministries, non-governmental organizations, the UN, the Food and Agriculture Organization (FAO), the Committee on World Food Security and the High-Level Panel of Experts (in parallel with their existing actions and demands to enhance humus content of our soils), and many others.

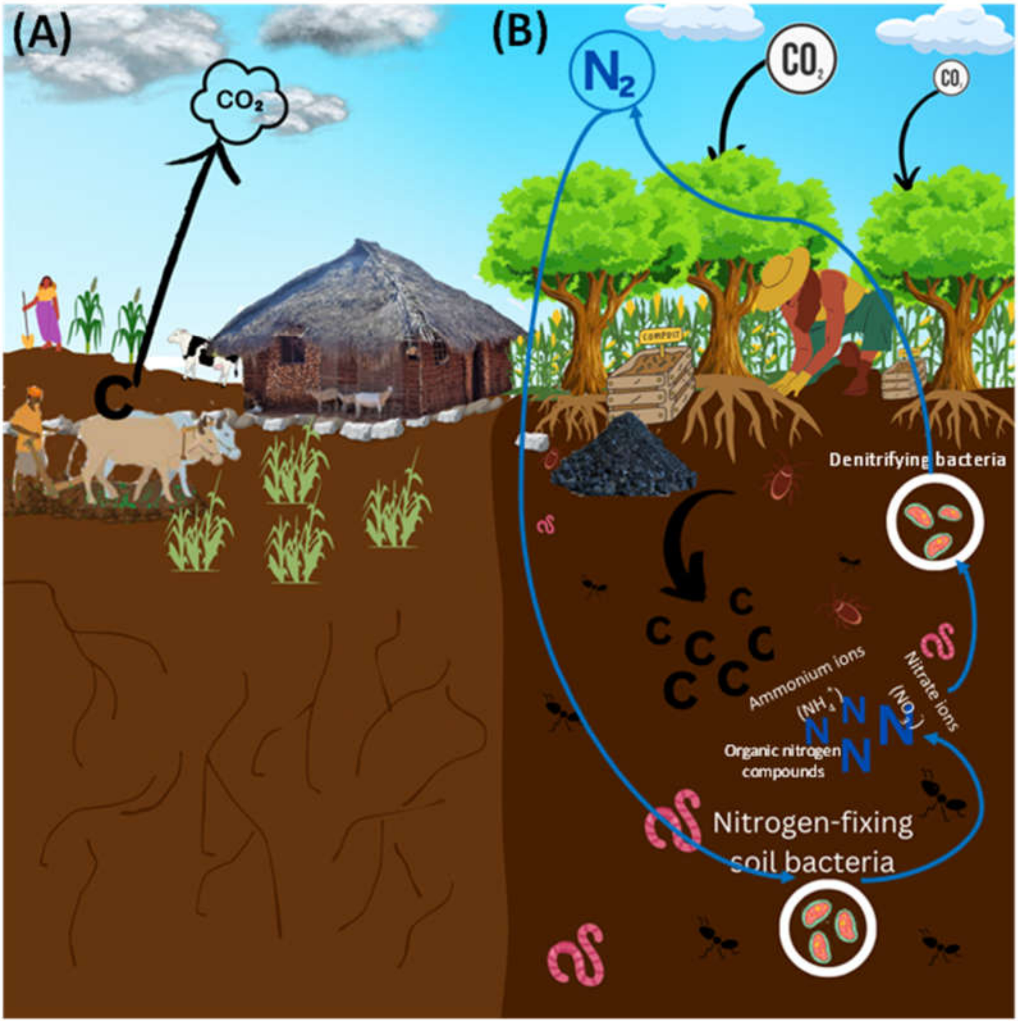

Figure 1. Schematic representation of (A) without betterSoil vs. (B) with betterSoil agricultural principles

As an organization, betterSoil is part of a universe of individual organizations and actors that already work on soil improvement; some even have experience for decades. Only the combined power of groups of politicians, investors, farmers, scientists, practitioners, and students can push our joint agenda forward. We welcome all individuals and entities to join a global movement for collaborative action to put scientific and indigenous knowledge into practice. Overall, healthy soils are the foundation of all life on earth, including your life as you read this paper! We are what we eat – and our food is either grown on healthy or non-healthy soil.

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