SCIENTIFIC PANEL
ON RESPONSIBLE PLANT NUTRITION

FERTILIZER AND SOIL HEALTH FOR ENHANCED PRODUCTIVITY AND SUSTAINABILITY IN SUB-SAHARAN AFRICA

Issue Brief 06,February 2024

KEY POINTS

1. SOIL HEALTH INDICATORS AND TARGETS: Soil health is commonly defined in relation to achieving sufficient crop yields while maintaining the future productive capacity of soils and the ecosystem services soils provide (Figure 1). Soil organic matter is a key soil health indicator, along with available P and K, soil acidity, and water-stable aggregation. There is no consensus yet on easily measurable, meaningful biological indicators.

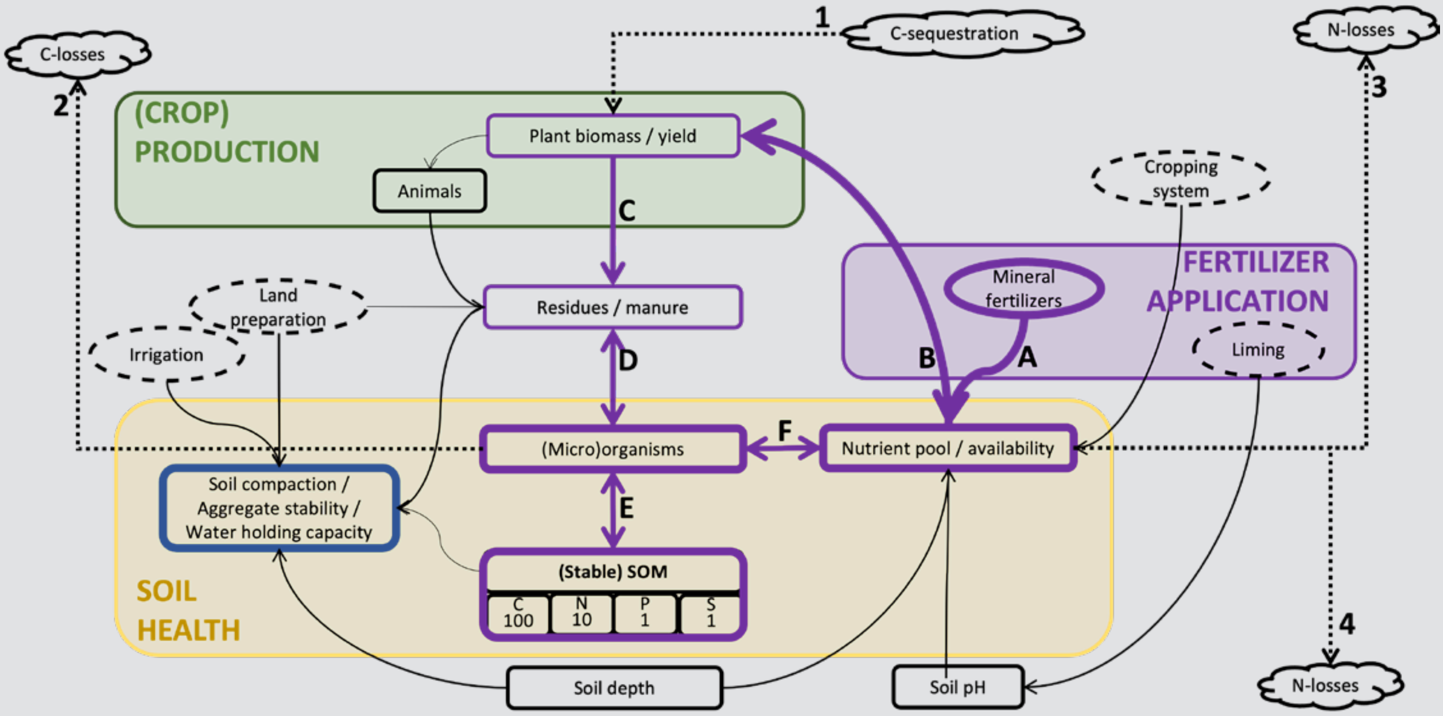

Figure 1. A general soil health framework for Africa. Rectangles are system components. Ovals present management interventions. Emissions and sequestration are presented as clouds. Arrows present processes connecting the components. The blue line relates to water availability and the purple lines indicate direct impacts of mineral fertilizers on biomass/yield and SOC. Dashed lines refer to atmospheric C or N losses or N leached beyond the crop root zone. Source: Vanlauwe et al. 2023 (1).

2. TOWARDS FERTILIZER AND SOIL HEALTH: Managing soil health in sub-Saharan Africa is complex:

- To bolster agricultural productivity, both fertilizers and organic inputs are essential sources of plant nutrients. Together with sound agronomic practices, superior seed varieties, soil amendments, and other measures, this forms the basis of Integrated Soil Fertility Management.
- On healthier soils, the efficiencies of both fertilizers and water tend to be higher. Hence, enhancing soil quality directly contributes to improved agricultural performance.
- Increased input of plant nutrients as inorganic fertilizers is indispensable for sustainable agriculture that seeks to increase food production and restore soil health. Relying solely on organic inputs often results in soil nutrient depletion and degradation.
- Building soil health and rehabilitating degraded soils are long-term processes; in stark contrast to the rapid depletion of soil organic matter and nutrients caused by practices such as land clearing or excessive nutrient removal.

3. ADDRESSING CLIMATE CHANGE REQUIRES CHOICES: Climate change affects the relationship between fertilizer and soil health. Technical, financial and structural support that addresses specific risks created by climate change will be essential for farmers to engage in sustainable fertilizer and soil health management practices. Such investments are likely to have a high return.

4. ENABLING FARMERS: Bottlenecks in engaging smallholder farmers in soil health-restoring practices are large upfront costs, the length of time required to achieve economic benefits, and access to affordable inputs. Fertilizer subsidies need to be re-designed with respect to soil health outcomes. Soil health is a public good, thus justifying greater public investment in it.

5. SOIL HEALTH INVESTMENTS REQUIRE LOCALIZED ACTIONS: Soil health management should always be localized and context-based. The specific solutions for building soil health depend on soil characteristics, environment, the farming system, crops grown, and socioeconomic abilities.

WHAT IS SOIL HEALTH?

Broadly speaking, soil health refers to the overall condition and quality of soil, including its physical, chemical, and biological characteristics that define the *capacity of a soil to function as a vital living ecosystem that sustains plants, animals, and humans (2)*. Healthy soil has good water-holding capacity, drainage, and resistance to erosion, a balanced pH as well as adequate levels of plant nutrients and organic matter. Moreover, healthy soil sustains a diverse community of soil organisms, such as bacteria, fungi, and fauna, which play important roles in nutrient cycling and maintaining or building soil structure. Based on these properties, soil health directly influences the productivity, resilience, and sustainability of agricultural and natural ecosystems.

Measuring soil health involves assessing a range of physical, chemical, and biological properties that contribute to soil fertility, productivity, and sustainability. Specific indicators describe soil health, depending on the context and management goals of the particular system:

- **Physical indicators:** These include soil texture, structure, porosity, water-holding capacity, and infiltration rate. Physical indicators can be measured using soil cores or pits, or instruments such as penetrometers, tensiometers, and soil moisture sensors.

- **Chemical indicators:** These include soil pH, nutrient levels (e.g., nitrogen, phosphorus, potassium, micronutrients), organic matter content, and cation exchange capacity. To measure chemical indicators, soil samples are analyzed in a laboratory, or using the crop nutrient status as an indicator of soil nutrient supplying capacity.

- **Biological indicators:** These include the presence and diversity of soil organisms, such as bacteria, fungi, earthworms, or nematodes. Biological indicators can be measured using techniques such as soil enzyme assays, microbial biomass measurements, and DNA analysis. Their interpretation in relation to specific soil functions of agronomic importance is, however, still challenging.

Combined, these indicators give a good idea on the health status of the soil. Several tools and protocols are available for quantifying soil health, including the Comprehensive Assessment of Soil Health *(3)*, the soil management assessment framework (4), regional guidelines for Europe *(5)*, or simplified national programs such as the Soil Health Card program in India (https://www.soilhealth.dac.gov.in). Generally speaking, validation of these tools in SSA has been limited.

The use of specific indicators and thresholds to quantify soil health depends on the functions that a soil is envisaged to support *(6)*. From an agronomic viewpoint, healthy soils increase crop yields by releasing nutrients, supporting water retention, facilitating root growth, and protecting crops from pests and diseases *(7)*. The content of organic carbon in the soil is of cross-cutting importance to its health status, as soil organic matter favorably affects all these properties.

The timely and sufficient availability of plant nutrients is particularly critical as they impact crop performance as well as soil health. For example, depending on the soil type, complex processes immobilize P in the soil and may thus hamper its availability. In SSA, exchangeable K is too low in many soils to achieve good yields of root and tuber crops. Soil acidity is another key indicator; crop growth is commonly limited at pH values below 5 and above 8. Physical indicators of soil health are generally related to the ease of root growth through the top- and subsoil and the regulation of water infiltration and storage. While it may be important to quantify or assess their impact on soil health, current microbial measurements are not easy to interpret and may not necessarily provide credible inferences about soil health status *(8)*. That said, progress has been made in Brazil, where soil bioanalysis (SoilBio) has been increasingly used by farmers (Box 1).

In addition to the need of specific indicators to assess soil health, three other aspects must be considered: (i) spatial heterogeneity of soil properties; (ii) the rate of change of some indicators; and (iii) the cost of measuring indicators over large areas of land *(9)*. Alternatively, instead of directly measuring soil health indicators, one could assess the change in crop and soil management practices as related to expected changes in the status of key indicators through empirical or mechanistic modeling.

Crop productivity directly depends on key indicators of soil health such as SOC, available P, exchangeable K, soil pH, or water-stable aggregation. In this Brief, we focus on soil organic carbon (SOC) because it is a central indicator of soil health and challenging to manage, whereas solutions to address low available P, K, S, micro-nutrients, and acid soils exist.

BOX 1: THE BRAZILIAN EXPERIENCE WITH INDICATORS OF SOIL HEALTH.
The economy in Brazil is strongly based on agriculture, so rebuilding soil fertility and maintaining soil quality/health are priority goals. For decades, chemical and physical parameters, including SOC, were evaluated searching for indicators of soil quality/health that are reliable and feasible for large-scale analysis. In the late 1990s, microbial parameters of biomass C and N and a metabolic quotient were suggested as interesting indicators; more effective and able to detect changes earlier than any chemical or physical parameters *(10)*. In a long-term study in the Cerrado region, a savannah region with many similarities to SSA, microbial indicators were interpreted as a functions of the relative cumulative yields of maize and soybean and SOC, and the critical levels were defined based on criteria similar to those used in soil nutrient calibration tests *(11)*. Subsequent studies found that only two enzymes, arylsulfatase and β-glucosidase, were associated with the carbon and sulfur cycles, respectively *(12)*. These two soil enzymes, in addition to routine chemical analyses, were integrated into a Soil Bioanalysis technology in 2020 *(13)*, which has been exponentially used by farmers to assess soil health. Consistent results obtained in two decades of studies in Brazil show that it may take years until changes in SOC are detected, whereas faster changes can be detected in microbial enzymatic activities.

WHAT ARE THE ISSUES?

1. FERTILIZER USE AND CROP PRODUCTIVITY HAVE INCREASED, BUT PROGRESS IS AND TOO SLOW

Agricultural production in sub-Saharan Africa (SSA) needs to urgently increase to ensure food and nutrition security of the growing population *(14)*. If intensification is not successful and massive expansion of agricultural land is to be avoided, SSA will become even more dependent on imports of cereals and other staples. In 2004, the then-UN-general secretary Kofi Annan called for a uniquely African Green Revolution to take root within the rich diversity of the continent. In 2006, the African Union, through the *Abuja Declaration on Fertilizer for an African Green Revolution*[1] recognized the critical need to enhance access to fertilizers to achieve an African Green Revolution and alleviate the poverty trap caused by poor and declining soil fertility. Yet, progress has been slow *(1, 15)* and the problem remains with a per capita yield decline in fertilizer use for many countries in SSA. While the average fertilizer nutrients use in SSA is still only 15 kg N+P2O5+K2O/ha in 2022 (excluding South Africa) some countries have approached or actually reached the Abuja target of 50 kg/ha. It is concerning, however, that average fertilizer consumption across SSA has stagnated since 2019.[2]

In Asia, agricultural production rose fast and was primarily driven by yield growth. Average cereal yields have more than tripled in the past 60 years, wherease cereal area only increased by about 20%. In Africa, on the other hand, crop yield growth has been slow whereas the harvested crop area more than doubled during the same period (Figure 2, left). Notwithstanding disappointing continent-wide figures, some countries in Africa have succeeded in increasing fertilizer use and have seen stark positive benefits. In Ethiopia, for example, maize yields nearly doubled in the past 20 years, mostly on existing land (Figure 2, right). Increased fertilizer, better varieties and other improvements drove that change.

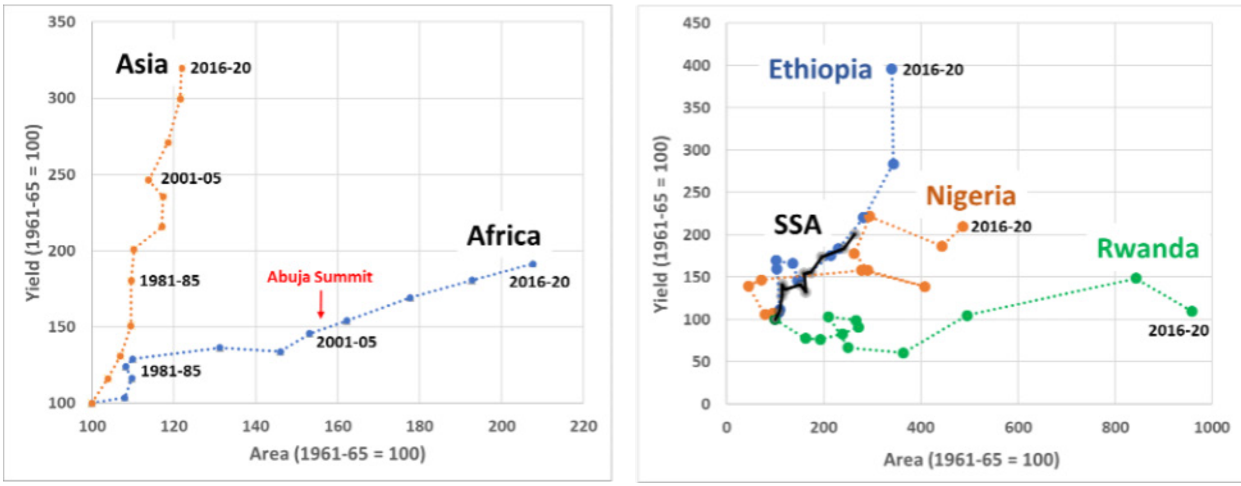

Figure 2. Relative changes in cereal grain yield and harvested area in Asia and Africa (Left) and maize yield and area in Sub-Saharan Africa (SSA), Ethiopia, Nigeria and Rwanda (Right), 1961-2020. Data shown are 5-year averages, with the average of 1961-1965 set as 100. Source: FAOSTAT (https://www.fao.org/faostat/).

Maintaining soil health is a globally relevant issue, but the situation in SSA is unique because large areas under smallholder farming continue to suffer from nutrient mining, eroding the productive capacity of large areas of agricultural soils. Sub-Saharan Africa remains the only world region with widespread negative nutrient balances that continue to increase over time, as illustrated for phosphorus (P)

1. https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/africa-fertilizer-financing-mechanism/about-affm/abuja-declaration
2. More information can be found at https://africafertilizer.org/

and potassium (K) in Figure 3. Actual nutrient balances are even more negative because losses due to removed crop residues, leaching, runoff, or erosion are not included in these estimates. However, significant differences exist among regions and countries in Africa, with West and Central Africa generally faring worst (Figure 3).

It is now widely accepted that producing crops at the cost of soil health becomes unsustainable poverty trap. Increasing crop productivity to meet current and future food needs and improving soil health in SSA will only be successful with the increased and efficient use of fertilizer nutrients *(16)*. A second African Fertilizer and Soil Health Summit is scheduled to take place in 2024 to draw up new plans for action.

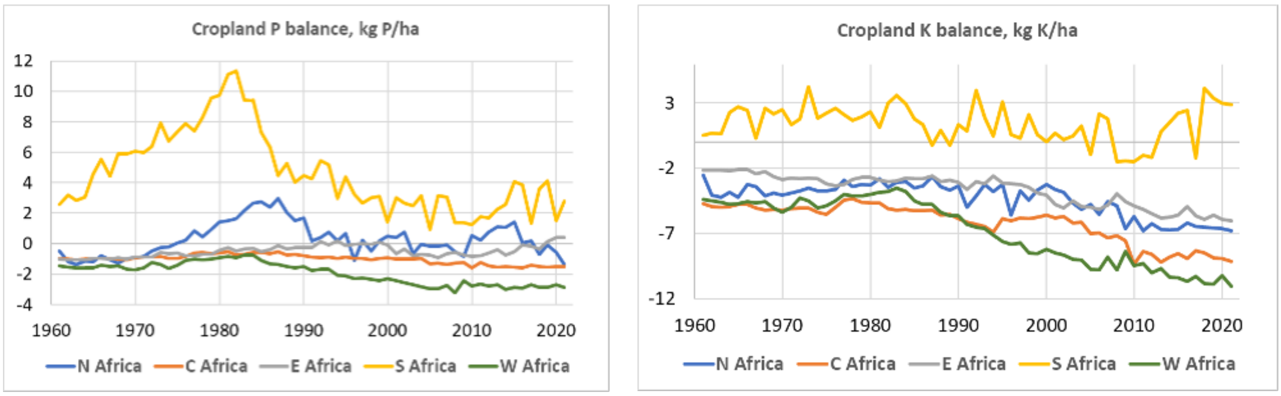

***Figure 3.** Cropland phosphorus (left) and potassium (right) input-output balances for different sub-regions of Africa, 1961-2021. Nutrient inputs include fertilizer, manure and seeds. Nutrient output refers to removal with the harvested crop product. Values shown are national averages for all crops grown, i.e. all cropland. Not included is grassland or other land uses. Source: FAO Cropland Nutrient Balance database (17).*

2. FROM FOCUSSING ON INCREASING CROP YIELDS TO RECOGNIZING SOIL HEALTH AS A PREREQUISITE FOR SUSTAINABILITY

In the 1980s and 1990s in SSA, increasing attention was directed to the needs of small-scale farms with a focus on the critical role of soil fertility and the widespread negative effects of negative nutrient input-output balances *(18, 19)*. To address the needs of smallholder farms and low-fertility soils, a soil management paradigm was articulated *(20)* that highlighed the need to 'rely more on biological processes to optimize nutrient cycling, minimize external inputs and maximize the efficiency of their use.' The initial focus was on using crop varieties that were adapted to adverse soil conditions, such as soil acidity and poor nutrient availability, and increasing the availability of organic inputs to complement fertilizer, with a strong emphasis on improved (leguminous) fallows or intercrops. Soil organic matter and the combined use of mineral fertilizers and organic inputs were emphasized as means to increase efficiencies of nutrient use. Concurrently, so-called low-external-input sustainable agriculture (LEISA) received much attention *(21)*. It became clear during this period that the low yields achieved without nutrient inputs could not address the critical issues of poverty and food security. Due to these concerns, the focus shifted toward replenishing soil fertility *(22)*.

The Integrated Soil Fertility Management (ISFM) paradigm *(23)* emerged in the 2000s, based on decades of soil and crop research in Africa. In contrast to earlier paradigms, ISFM recognizes the critical need to use all organic and mineral nutrient resources efficiently and focus on using fertilizers as entry points to intensifying smallholder agriculture. It follows a stepwise approach to rehabilitate, improve, and rebuild soils. First, fertilizers and improved crop varieties are applied to raise productivity and rebuild the fertility base of the soil. The next step is to incorporate organic inputs into soil management to rebuild the soil organic matter pool, which is key to soil health and integral to multiple soil functions. Legume inoculation with N-fixing bacteria (rhizobia) is another measure because it improves legume yield and thus the in-situ availability of organic inputs in the form of crop residues *(24)*. There is scope to deploy various bio-stimulants to increase crop yield and residues *(25)*, though care needs to be taken since many ineffective bio-stimulants are currently available in SSA *(26)*. Other amendments or practices such as lime application, water harvesting, or deep tillage, are also included to address local constraints.

Over the past two decades, major investments were also made to promote conservation agriculture, largely driven by concerns about soil erosion and loss. Smallholder farmers, however, often lack the means to implement the commonly recommended three pillars of conservation agriculture *(27)*: (i) minimizing soil disturbance through tillage; (ii) maintaining a continuous soil cover; and (iii) diversifying crops. To ensure sufficient crop production, a fourth principle for conservation agriculture was proposed later on: using mineral fertilizer appropriately *(28)*. Conservation agriculture has been most successful in world regions such as South and North America or Australia *(29)*, which all have in common that farms are larger and farmers have accees to modern technology, including suitable machinery, high-quality seeds, fertilizers, good weed, diseases and pest control. In contrast, farmers in Malawi rarely practiced all the principles of conservation agriculture concurrently and benefits hardly occurred *(30)*.

More recently, 'agroecology' and 'regenerative agriculture', which consider other ecosystem services besides crop productivity as equally important, have received increasing attention. Soil health is viewed as a key indicator for the delivery of those other services. Regenerative agriculture favors practices that (i) encourage water infiltration and prevent soil erosion; (ii) build soil organic carbon (SOC)[3] and enhance biological nutrient cycling; (iii) foster plant diversity; (iv) integrate livestock; and (v) reduce reliance on external inputs *(31)*. Applying these ideas to the typical farming situations found in SSA faces major shortcomings *(32)* because plant nutrients first need to

3. In this document, we refer to soil organic carbon (SOC), noting that soil organic matter (SOM) is constituted of organic compounds that contain C, N, and other elements. In that sense, SOC is a measurable indicator of SOM. Since the current document refers both to SOM as a property that hosts several functions and to SOC as an element that can be managed by soil management practices, we decided to refer only to SOC in the text, noting that the amount of SOC and SOM is strongly correlated in most circumstances.

be made available in order to reach many of the goals of regenerative agriculture.

In summary, the Green Revolution has allowed increased food production to exceed global population growth over the past decades, except in SSA. As a region, SSA experienced many decades in which agricultural concepts and practices were promoted that neither benefitted soil health nor farmers and food consumers. It is now urgent to correct that and focus on the things that must come first to sustainably intensify agriculture, while also recognizing the increasing awareness of environmental and societal challenges associated with food systems *(16)*. Managing nutrients for soil, crop, and human health is of highest priority for SSA.

4. FERTILIZER AND SOIL HEALTH – FRIENDS OR FOES?

Fertilizer application, crop productivity, and soil health are intertwined (Figure 1). Crop biomass as feed for animals and food for humans (top left box in Figure 1) is produced upon sufficient availability of light, water, and nutrients. Large amounts of plant nutrients are removed from farmers' fields with crop export and consumption. Healthy soils (bottom box in Figure 1) comprise favorable physical, chemical, and biological properties with multiple interacting processes. Soil organic matter consists of plant, animal, and microbial residues at various stages of decomposition as energy and nutrient sources for (micro)organisms. Fertilizers (top right box in Figure 1) boost growth by providing nutrients to support plant productivity and carbon fixation.

Using fertilizers is essential to increase crop yields and hence the production of organic residues, raising SOC and sequestering and storing N, P, and S in soil. On average, every 1% annual increase in crop yields results in a 0.3% annual increase in SOC stock across Africa, Asia, and Latin America (Figure 4). The large scatter in that relationship indicates that many other factors besides increased crop yields affect changes in SOC, i.e. additional practices are needed to ensure that increased crop yields and biomass production improve soil health.

Whereas long-term application of fertilizers in temperate climates increases or maintains SOC *(34, 35)*, research on the impact of fertilizer use on SOC in the cropping systems in SSA is still scant. General indications suggest that under current productivity levels common soil health-promoting practices are not increasing SOC *(36)*. By reviewing the effect of fertilizer on SOC, Beillouin et al. *(37)* found only one meta-analysis covering experiments in SSA *(38)*, which also showed no significant effects of fertilizer on SOC (Figure 5). Similarly, a recent review of 25 long-term experiments conducted in SSA with contrasting climate, soils, and mineral fertilizer inputs also revealed no clear evidence that fertilizer application had much impact on maintaining SOC (Figure 6).

Probably, lower crop yield levels (and thus C inputs) in SSA explain the different trends observed in croplands globally. Besides, only few of the included studies were carried out for five or more years and it is likely that under conditions of higher productitivity different results may be achieved. Another way to increase SOC is through biomass transfer, i.e. applying organic inputs that have been produced outside the plot. This may, however, not represent a net benefit if it leads to depletion of soil health on the land on which this biomass was produced. There are indications, however, that including soybean can improve SOC content and land productivity *(39)*.

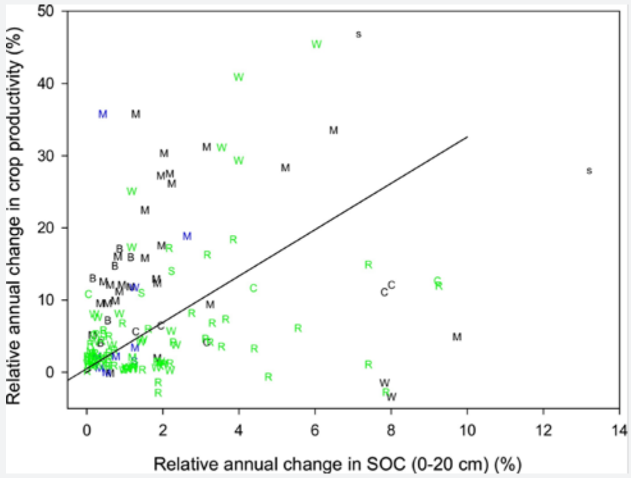

__Figure 4.__ Relative annual changes in crop productivity and soil organic carbon stock (over 0 20 cm) (%) after changes in land management practices (33). Crop species (symbols): B, beans; C, cassava; M, maize; P, sweet potatoes; R, rice; S, soybean; s, sorghum; W, wheat. Regions: Africa (black); Asia (green); and Latin America (blue). The solid line is the standard major axis regression for all data points (y=0.495+3.21x; r=0.205, P<0.012).

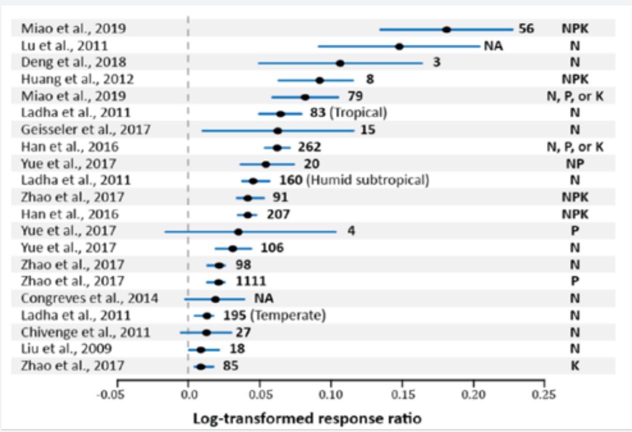

__Figure 5.__ Synthesis of meta-analyses evaluating the effect of fertilizers on SOC. Studies are from all world regions. Chivenge et al. 2011 (38) is the only study covering experiments in SSA. Fertilizer inputs are indicated as N - nitrogen; P - phosphorus; and K - potassium. Data points represent the mean effect size, and error bars represent confidence intervals. Numbers represent paired data (no. of cases) used in a given meta-analysis. Source: data from the evidence map of Beillouin et al. (37).

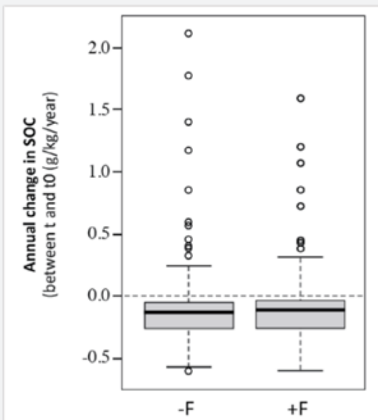

__Figure 6.__ Boxplot of annual change in SOC between the end and the start of the long-term experiment in the treatment with fertilizer (+F) and the control (-F) for 25 long-term experiments in sub Saharan Africa. Source: M. Corbeels et al., unpublished.

5. LIMITATIONS TO INCREASING SOIL ORGANIC CARBON

To what extent can SOC be increased in reality and under the conditions of SSA? Soil organic carbon under natural vegetation could be viewed as an attainable SOC level for a given soil and climate combination. While the native SOC in undisturbed sites provides some general guidance for the C sequestration potential of soils, it is not a realistic goal for SOC restoration under agriculture. Natural ecosystems are not meant to produce and export much biomass, but are dominated by plant species that allocate much of their carbon to roots, which are primary sources for forming stable soil organic matter. As such, attainable SOC restoration under agriculture may realistically reach only 60 - 70% of its natural potential *(40)*.

Decomposing organic material releases large amounts of CO2, such as after land clearing. Hence, through continuous cultivation and with limited to no mineral or organic inputs, the carbon content of the soil continues to decline. That said, even soils under commercial agricultural practices do not restore SOC to the levels seen under natural vegetation (Figure 7). Whether this observation is a major issue or not depends on the amount of SOC that is required to maintain critical ecosystem functions for the intended land use, as affected by soil properties and climatic conditions -- a question that is still awaiting a conclusive answer. One could also argue that the function of soil and its impact on the ecosystem has changed as land management changed from natural vegetation to agriculture and therefore a lower SOC became acceptable.

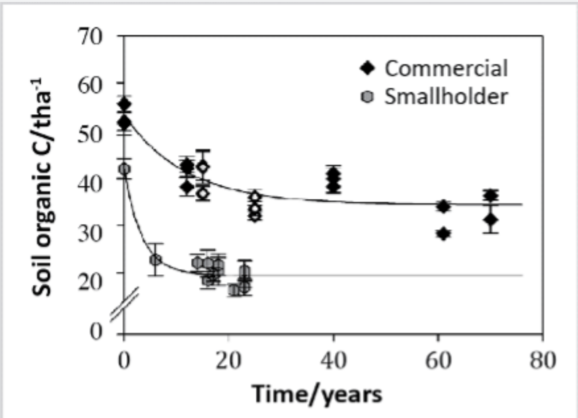

***Figure 7.** Changes in soil organic C following clearing of woodland, as affected by duration and intensity of farming at Chikwaka, Zimbabwe(41).*

Increasing SOC contents is an option for soils in Africa that have the capacity to stabilize soil organic matter, such as clay soils with high oxide contents that are common in large areas of Africa. African soils can be important C sinks since they have experienced a massive decline in SOC, mainly as a result of low C inputs into soil. Applying organic inputs can increase SOC, yet limited availability of such organic inputs is a constraint. Adding organic matter from external sources is limited in scope and may lead to C depletion in the areas where this organic matter was collected. Hence, the application of fertilizer is a more realistic path towards increasing SOC through growing larger amounts of biomass in-situ, particularly roots. For soils to form stable SOM each ton of soil carbon must also contain about 100 kg of N, 10 kg of P, and 10 kg of S *(42)*.

6. ECONOMIC REALITIES

Although fertilizers are key components of sustainable food systems, their use in Africa is heavily constrained by precarious politics. Fertilizer use varies greatly between and within countries as a result of differences in both micro- and macroeconomic conditions. Moreover, biophysical conditions, such as the amount of rainfall and soil type, are important; the risk of crop failure resulting from low rainfall is a strong disincentive to the purchase and use of fertilizers on subsistence crops.

Across SSA, crop yields are much lower than what is attainable given the environmental conditions (soil and weather) and with good technologies, which is also referred to as an ecological yield gap. In fact, yield gaps in smallholder agriculture in SSA are the largest in the world *(43)* and low use of fertilizers combined with low fertilizer use efficiency are among the major causes of that *(44)*. Closing the yield gap in SSA is the primary route for improving food security and the well-being of rural households *(14)*, while farmers in SSA will need to use much more fertilizer than they currently use.

However, even though it may be technically feasible to increase crop yields in many regions of SSA, it is not always economically viable for farmers because of relatively high fertilizer prices and relatively low crop produce prices. Location-specific ecological and economic conditions greatly affect crop response to fertilizer and economic returns on fertilizer investments *(45)*. The latter study showed that (i) the average economic yield gap (the difference between current yield and profit-maximizing yield) was about 25% of the ecological yield gap; (ii) though maize yields could be profitably doubled, the economic incentives to do so are weak due to unfavorable input:output price ratios; and (iii) risk from variable seasonal rainfall makes this worse. Considerable variation in these fertilizer profitability calculations exists within countries, emphasizing the need to tailor fertilizer recommendations based on the local environmental and economic conditions.

Variations in agricultural technology adoption can be attributed to differences between farmers, farms, and the environments in which they operate. Farmers are less likely to apply fertilizers if the risk of non-response or non-profitable response is high, fertilizer prices are too high (and there is no government support), or crop prices are too low.

Land is another key factor for crop production. Farmers with large farm sizes and land ownership are likely to invest in fertilizers and soil health practices. They are also likely to have significant or adequate amounts of organic matter resources. Farmers without secure land tenure are less likely to invest in fertilizers or other soil health practices than those who have more certainty to reap the medium to long-term benefits *(46–48)*. Farmers who own land are also able to access credit as a pre-requisite for investing in technologies. A farmer's age, gender *(49)*, and education level are other mediating factors affecting the uptake of technologies and correspond to the farmer's knowledge, ability, preferences, and risk appetite. While this is an important topic, directly affecting the use of fertilizer and its impact on soil health, a detailed analysis of the factors underlying this topic is out of scope of the current paper.

SOLUTIONS AND NEEDED ACTIONS

A number of solutions and actions are required to ensure that fertilizers are used efficiently and their applications result in increased crop yields, while soil health is maintained or even improved.

1. **Consensus on what constitutes soil health, based on specific functions and environments:** A key performance indicator framework is required that defines soil health and the key functions of a healthy soil for the intended land use. Such indicators need to be measurable and interpretable in relation to the key soil functions, as well as to the management practices affecting them. Soil organic carbon is generally acknowledged as a key indicator. Besides SOC, available P, exchangeable K, soil acidity, and water-stable aggregation should be included in the list of key indicators for soil health in relation to crop productivity in SSA. Currently, there is no consensus on easily measurable biological indicators, notwithstanding progress being made elsewhere (Box 1). Where necessary, additional soil or crop indicators may be used to quantify soil supplying capacity of specific plant nutrients, including micronutrients.

2. **Monitoring schemes to assess progress and support soil health management:** National or regional monitoring schemes should support public investments in soil health by monitoring change over time and space. Such soil information should be openly available, thus also improving digital soil information resources across Africa (50). Another important route is soil health monitoring as part of vertically integrated supply chains, for example in relation to sustainable production standards implemented by companies. Harmonized and scientifically sound soil health assessment frameworks need to integrate globally accepted standard operational procedures and data management systems, implemented by public extension agents as well as private sector agronomists.

3. **Raising awareness on how farmers and society benefit from improved soil health:** Soil health benefits society as a whole by providing and regulating numerous ecosystem services. Smallholder farmers benefit from the health of soil as crop yields increase and production systems become more efficient, ultimately leading to better returns on investment. Soil health is also a public good. Hence, investing in soil health, informed by actual quantification of these benefits, means ultimately investing in public health. Soil health only changes meaningfully over longer periods of time. Hence, longer-term incentive schemes are needed, partly supported by public funding, to enable farmers to invest in soil health management. In this same context, it is also important to make the public aware that well-managed fertilizers do not 'kill' soil — a misconception regularly reaching public discussion fora in SSA — but are actually essential for good soil health.

4. **Technical, data-driven solutions to improve soil health beyond beliefs and wishful thinking:** Improving soil health is a laudable and necessary goal of an agricultural transformation agenda, yet not always easily achievable. For examle, soil health improvement is limited by poor nutrient retention in sandy soils. Similarly, specific agronomic practices are assumed to improve soil health, e.g., as is often the case for conservation agriculture, but they are not always universally applicable. Evidence often suggests that gaining soil health depends on many other factors that need to be embedded in improved, locally adapted practices.

5. **Include investments in fertilizer and soil health in climate adaptation or mitigation:** Climate change affects the relationship between fertilizer and soil health. De-risking agriculture will be essential for farmers to engage in fertilizer and soil health management practices while addressing specific hazards created by climate change. Investments in soil health improvement also contribute to increased farming system resilience through adaptation and mitigation.

6. **Implement policies that enable farmers to invest in soil health:** Land tenure is key, but farmers in SSA will also continue to require fertilizer subsidies since there are no alternative sources to provide the amount and diversity of nutrients needed to grow crops. Redesigning fertilizer subsidies is crucial with respect to soil health management. Such subsidies need to be designed smartly, and include educating farmers on how to maximize the use efficiency of the input and how to manage locally available organic resources and crop residues in combination with fertilizers.

WHO NEEDS TO DO WHAT?

The global fertilizer industry needs to integrate aspects of soil health management in fertilizer recommendations and ensure that the right fertilizer formulations are available for the right crops and soils to maximize crop biomass production. Co-supply of fertilizers and effective bio-stimulants could provide an entry point for the increased use of the latter.

Service providers need to integrate knowledge on soil health management practices into agronomic advisory services and share the information efficiently with farmers.

Scientists need to identify and characterize key indicators for soil health, and practical protocols and tools for rapid and efficient monitoring of soil health status. They should further characterize agronomic practices that restore or maintain soil health under different environment and management conditions. Soil health monitoring systems need to be set up to capture changes in soil health conditions as related practices move to scale.

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Policy makers need to facilitate farmers to invest in soil health improvement, which is a longer-term objective that requires public support, including redesigned fertilizer subsidies. Lessons learnt from countries that released policies related to payment for SOC sequestration in soil could form a basis for developing similar policies in SSA. Organic waste stream management and use can be another route towards increasing the availability of organic inputs, especially in rural areas near urban centers. National and/or regional soil health monitoring units with the necessary expertise and tools need to be established and maintained.

Investors need to integrate soil health management as a key condition for financial support and support the implementation of soil health-promoting financial mechanisms. Sustaining public support to facilitate farmers' investments in soil health will be required in the medium to long-term to build soil health to reasonable levels.

Civil society organizations need to raise awareness across all sectors of society on the importance of soil health, the role of nutrient inputs, both organic and mineral, as well as its maintenance and improvement. They need to show how improving soil health can counteract climate change-related stresses, yield decline, and environmental degradation. Their work should be based on scientific evidence, not ideology or beliefs.

The retail sector needs to include soil health-positive production practices in their processes for certifying responsible production.

Consumers are encouraged to buy soil health-positive food and actively engage in discussions related to soil health, as is currently done in relation to climate change.

WHAT WOULD SUCCESS LOOK LIKE?

Access to soil health management information and practice is facilitated: Integrated Soil Fertility Management (ISFM) is mainstreamed into agricultural development programs. Fertilizer subsidy schemes include support for soil health management practices in the context of ISFM, including aspects of 4R for fertilizer management. Funders provide medium to long-term support to soil health improvement in their respective agricultural development programs. At least 70% of smallholder farmers on the continent are accessing targeted agronomic recommendations for specific crops, soils, and climatic conditions to ensure greater efficiency and sustainable use of fertilizers.

A more diverse range of fertilizer products and organic inputs is available and affordable: The domestic production and distribution of fertilizer and organic inputs is tripled within the next 10 years thus enabling access and affordability for smallholder farmers. To improve production, procurement, and distribution of fertilizer and organic inputs, the Africa Fertilizer Financing Mechanism (AFFM) is fully operational. Policies and regulations are formulated and implemented to create a conducive environment for fertilizer and soil health interventions.

Soil health conditions are improving as an outcome of the African Fertilizer and Soil Health Summit of 2024: Consensus is reached on key indicators related to soil health, standard operational procedures for measuring these together with trends or thresholds indicating positive change. Upon uptake of soil health management practices, many smallholder farming systems in SSA register positive change at scale. The agronomic efficiency of fertilizer is doubled (e.g., from 10 to 20 kg maize grain per kg fertilizer nutrient) with marked increases in crop yields and crop residue availability, thus also increasing the in-situ availability of organic inputs for improving soil health. At least 30% of degraded soil is restored within 10 years.

Advisory and extension services integrate soil health management information: Advisory services are up to date about fertilizer and soil health management, supported by a large network of certified agronomists providing bundled services to farming communities. Feedback on the performance of agronomic practices informs the R&D community to further improve the efficacy and efficiency of specific recommendations.

National and regional science capacity is capable of generating and disseminating locally relevant soil health management recommendations: Science capacity is strengthened at the national and regional level, especially in areas such as data science, advanced analytics, and artificial intelligence, thus supporting the development, validation, and dissemination of site-specific, local recommendations. Effective linkages are established between the R&D community, service providers, and last-mile delivery staff.

Public awareness and support: The public is aware of the role of soil health in addressing many of the challenges faced by farmers and by society as a whole, and appreciates the role of both fertilizer and organic nutrient inputs in maintaining and improving soil health. The retail sector is adopting soil health-positive certification schemes and consumers are preferably buying soil health-positive products.

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Citation: Scientific Panel on Responsible Plant Nutrition. 2024. Fertilizer and soil health for enhanced productivity and sustainability in sub-Saharan Africa. Issue Brief 06. Available at www.sprpn.org

Acknowedgement: This brief is based on a technical background document, prepared for the African Fertilizer and Soil Health Summit, to be held in Nairobi in 2024 (1).

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