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TOWARDS SUSTAINABLE INTENSIFICATION: INSIGHTS AND SOLUTIONS BRIEF NO. 2

# HEALTHY SOILS FOR PRODUCTIVE AND RESILIENT AGRICULTURAL LANDSCAPES

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IN PARTNERSHIP WITH:

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## SERIES INTRODUCTION

Raising global food production is essential to eradicate hunger and achieve food and nutrition security. But agriculture has become the world's single largest driver of environmental degradation, and it is pushing Earth beyond its natural boundaries. **Sustainably feeding future generations requires a fundamental shift in global agriculture.**

Since its inception in 2012, the CGIAR Research Program on Water, Land and Ecosystem (WLE) has developed scientific evidence and solutions for **sustainably intensifying agriculture**. For WLE, sustainable intensification means more than minimizing agriculture's environmental footprint; it means making sure that agriculture adds value to the environment, while it supplies global populations with sufficient food, nutrition and income.

More than 500 million smallholders worldwide stand to benefit from sustainable intensification of agriculture. Historic commitment to the UN Sustainable Development Goals (SDGs) and the Paris Climate Agreement further highlights the need for investing in sustainable and resilient agriculture.

But achieving sustainable, healthy food systems requires identifying **incentives** for sustainable farming. Likewise, it hinges on social and institutional innovations to **mitigate trade-offs and achieve synergies**, and **enable equitable access** to knowledge and resources. Not least, integrated solutions that work across sectors, disciplines and scales will be essential to realizing such a fundamental shift. Such innovations are what WLE has worked to develop. The Program's findings are summarized in this series of briefs, titled ***Towards sustainable intensification: Insights and solutions***.

### Key Reading

Rockström, J.; Williams, J.; Daily, G.; Noble, A.; Matthews, N.; Gordon, L.; Wetterstrand, H.; DeClerck, F.; Shah, M.; Steduto, P.; de Fraiture, C.; Hatibu, N.; Unver, O.; Bird, J.; Sibanda, L.; Smith, J. 2017. Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio* 46(1): 4-17.

# DEFINITIONS

**Carbon sequestration –** sequestration of soil organic carbon (SOC), see below, is the process by which carbon is fixed from the atmosphere via plants or organic residues and stored in the soil. When dealing with $CO_2$, SOC sequestration involves three stages: 1) the removal of $CO_2$ from the atmosphere via plant photosynthesis; 2) the transfer of carbon from $CO_2$ to plant biomass; and 3) the transfer of carbon from plant biomass to the soil where it is stored in the form of SOC in the most labile pool (FAO 2017). In principle, the amount of SOC stored in a given soil is dependent on the equilibrium between the amount of carbon (C) entering the soil and the amount of C leaving the soil. The capacity of soils to store C is limited and organic C contents of soils in pristine ecosystems are largely at equilibrium, i.e., the release of $CO_2$ by soil organic matter (SOM) decomposition and new formation of SOM by organic matter input from plant debris balance each other (Sommer and Bossio 2014).

**Circular economy –** reduces waste and avoids pollution by making use of materials that would otherwise be considered waste. In agriculture these materials include agricultural residues, animal excreta, food waste and human excreta. In a circular economy the resources in these 'wastes', including nutrients, organic matter and water, are returned to agriculture either directly or after processing.

**Nutrient recycling –** is the return of the nutrients used by plants back into the soil. This may take place through the direct return of crop residues to the soil, the direct application of animal manure or the use of organic fertilizers derived from plant material or animal or human excreta.

**Soil nutrients –** soil contains a number of elements that plants require for growth, these are termed nutrients. They include the macronutrients nitrogen (N), phosphorus (P) and potassium (K) as well as calcium, magnesium and sulfur and several trace elements that are needed in very small quantities.

**Soil organic carbon –** a summarizing parameter including all of the carbon forms, from dissolved to total organic compounds in soils (ISO 2013; FAO and ITPS 2015). Soil organic carbon is a general term for the total of all the different non-living organic compounds in the soil (excluding dead plants and animals). The organic carbon in the soil is used by plants for nourishment as they grow, and the plants themselves replenish the resource when they decay after they die.

**Vermicompost –** is the product that results from using earthworms for composting organic waste and sewage sludge. The earthworms consume the organic matter and produce vermicasts. The vermicompost is a mixture of composted organic matter and vermicasts and is considered a high-quality organic fertilizer (Misra et al. 2003).

## SUMMARY

**Healthy soils are essential for productive and resilient agricultural systems. They are also increasingly recognized as a means to mitigate climate change risks. While solutions for restoring degraded soils and landscapes do exist, improved knowledge and tools are needed to enhance their impacts over time and at scale. WLE has assessed the impacts of various land restoration initiatives and developed a range of tools to better tailor and target investments and interventions to local contexts.**

### Recommendations

- Carefully target soil and land management challenges and solutions to suit local conditions: New assessment and monitoring tools help identify where soil fertility problems are most severe and target appropriate interventions for maintaining or increasing organic matter and improving soil fertility.
- Encourage farmer investments in land and soil management practices through incentive mechanisms: Subsidies, reward mechanisms, and linking natural resource management interventions with market opportunities and income-generating activities can both improve soil health and create benefits for individuals and society in general.
- Support a circular economy: Bring otherwise 'wasted' nutrients back into the agricultural production cycle through tested mechanisms to convert domestic and agricultural waste into safe, nutrient-rich fertilizer.
- Move away from reactive restoration efforts and adopt preventive approaches: New information resources on soil and land conditions and management options can facilitate more proactive approaches to maintain soil and land health and reverse degradation risks.

## INTRODUCTION

Soil health is a prerequisite for long-term, sustainable agricultural productivity. Although large uncertainty about the numbers still exists, it is estimated that globally, two billion ha—23% of land under human use—are degraded, negatively impacting ecological integrity and agricultural productivity.

Achieving food security, healthy ecosystems and climate change mitigation benefits requires understanding the value and impacts of land restoration efforts over time and at different spatial scales; knowledge of how and where to target interventions; and tools to assess and monitor soil properties, health and degradation.

### The cost of land degradation

Agriculture is the main source of livelihood for 70% of the world's poor, who live in rural areas (World Bank 2017). The depletion and degradation of land and water resources pose significant challenges to the sustainability of farming systems as well as to the food, income and employment they provide. Major farming systems in South Asia and sub-Saharan Africa, including the Sahel, are already compromised by soil nutrient depletion. Population growth and climate change place further pressure on these fragile systems.

The annual global cost of land degradation, caused by land use change, land cover change or poor land management practices on static cropland and grazing land, is estimated to be about USD 300 billion (Nkonya et al. 2016). Land degradation impacts the health and livelihoods of 1.5 billion people worldwide, often disproportionally affecting women and the poor (FAO 2011). In sub-Saharan Africa, loss of soil fertility has caused average grain crop yields to stagnate at about 1.0 to 1.5 tons per ha since the 1960s (Sommer et al. 2015), and the financial cost of degraded agricultural lands in the region has been estimated at USD 68 billion per year, reducing agricultural GDP by about 3% annually (Zingore et al. 2015).

Conversely, the potential benefits from restoring degraded lands are significant. A range of land restoration interventions exist (Box 1), which vary in cost from USD 20 to USD 4,000 per ha for establishment and USD 22 to USD 286 per ha for maintenance. Many of these are low-cost, low-tech options, and restoring just 12% of degraded agricultural land could increase smallholder incomes by USD 35-40 billion and sufficiently boost agricultural output to feed 200 million people per year within 15 years (UNCCD 2016).

BOX 1. EXAMPLES OF SOIL AND LAND RESTORATION PRACTICES

**Soil and water conservation (SWC):**
SWC practices include soil fertility and crop management, soil erosion control measures and water harvesting. According to the World Overview of Conservation Approaches and Technologies (WOCAT), these activities can be broadly categorized as (i) agronomic, e.g., mulching, manure; (ii) vegetative, e.g., grass strips, agroforestry; (iii) structural e.g., terraces; and (iv) management, e.g., leaving land fallow (WOCAT 2007).

**Sustainable land management (SLM):**
SLM practices relate to the management of soil, water, vegetation and land systems. These practices include many of the same interventions as SWC, but with a broader aim of improving agricultural productivity, livelihoods and ecosystem services (Sommer et al. 2015; WOCAT 2007).

Traditionally, research and interventions on the restoration of degraded landscapes have emphasized SWC practices to control soil degradation and enhance productivity. Since the 1990s, however, there has been greater recognition of the range of interconnected factors beyond the farm scale that influence land management decisions as well as of the wider benefits that can be achieved from adopting SLM practices at the landscape scale, including carbon sequestration and nutrient recycling.

## Lessons from land restoration efforts in Africa

Land degradation is a major challenge worldwide, but the impacts on crop and livestock systems are most severe in sub-Saharan Africa, where nearly a third of agricultural land is degraded due to low nutrient application, soil erosion and acidification.

The Ethiopian Highlands are no exception. Here, an estimated 1.9 billion tons of soil are lost each year, and the resultant loss in soil nutrients has reduced land, crop and livestock productivity, costing an estimated 2-3% of the country's annual agricultural GDP. The impact is also felt in neighboring countries, including Sudan and Egypt, where annual costs to remove sediments out of water reservoirs range from USD 280 to USD 480 million (Gebresilase and Amede 2014).

The Ethiopian government has pledged to restore 15 million hectares of degraded lands by 2020 through investments in a range of land, soil and water management practices. Interviews conducted with farmers after these investments were implemented in watersheds located in Ethiopia's Tigray, Oromia and Amhara regional states suggest that SWC measures improved farm incomes by 50% on average, doubled crop productivity and fodder availability and halved the risk of crop failure due to moisture stress and climate shocks in some watersheds (Gebregziabher et al. 2016). SWC efforts have also reduced stormwater runoff and sediment yield (Table 1), and increased infiltration and groundwater recharge (Gebresilase and Amede 2014; Addisie et al. 2015; Mekuria et al. 2015).

Exclosures have also been found effective in rehabilitating degraded land in this region (Mekuria and Aynekulu 2013; Milne et al. 2016). Exclosures are land plots that have been closed off from people and domestic animals to protect against their interference. Research has found that establishment of exclosures on communal grazing land results in higher plant species richness and increased aboveground biomass and carbon. The net present value of the aboveground carbon sequestered in exclosures ranged from USD 6.6 to USD 37 per ha and increased with exclosure duration (from one to seven years). Households report benefiting from increased fodder production and reduced soil erosion, but expressed the desire for a mixture of exclosures and communal grazing to maximize livelihoods benefits (Mekuria et al. 2015, 2017).

Researchers have identified a wide range of interconnected factors – hydrologic, institutional and social – that influence local land management decisions and the success of land restoration interventions. Key among these are strong community participation and responding to local demands. Top-down approaches frequently fail to incorporate the knowledge, capacity and expertise of local communities. Incentive mechanisms, such as subsidies, reward mechanisms and linking natural resource management interventions with market opportunities and income-generating activities, can encourage farmer investments in land management practices that create benefits for both individuals as well as for society in general. Subsidies and reward mechanisms are justified because of these

TABLE 1. EFFECTS OF SWC MEASURES IN REDUCING RUNOFF AND SEDIMENT YIELD IN THE DEBRE-MAWI WATERSHED IN NORTHWESTERN ETHIOPIA

| | AVERAGE RUNOFF (MM) | | | AVERAGE SEDIMENT YIELD (T HA$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | BEFORE SWC | AFTER SWC | % REDUCTION | BEFORE SWC | AFTER SWC | % REDUCTION |
| **Weir 1** | 95 | 71 | 26 | 3.3 | 1.8 | 45 |
| **Weir 2** | 242 | 155 | 36 | 16.1 | 6.3 | 61 |
| **Weir 3** | 110 | 74 | 32 | 6.6 | 2.6 | 61 |
| **Weir 4** | 160 | 101 | 37 | 16.0 | 3.9 | 76 |
| **Weir 5** | 272 | 78 | 71 | 62.1 | 11.6 | 81 |

*Source:* Mekuria et al. 2015. *Note: before SWC measures refers to the mean values for the years 2010 and 2011. After SWC measures refers to the mean values for the years 2012-2014.*

social benefits (public goods). Finally, addressing institutional barriers, such as a lack of clarity on land tenure and improving the availability of information on soil and land conditions, can facilitate a move away from reactive rehabilitation efforts to more proactive, preventative approaches to maintaining soil and land health (Mekuria et al. 2015; Cordingley et al. 2015; Snyder et al. 2016; Adimassu et al. 2015; Baker et al. 2015; Shepherd et al. 2015; Steiner et al. 2015).

### Tools, insights and options for future investments

WLE research on soil organic carbon, water and nutrient efficiency, and soil health surveillance has contributed new insights and options for maintaining and restoring healthy landscapes. This research has been used to develop tools, maps and information that can help decision makers and investors better target and tailor interventions for more resilient and productive agricultural landscapes.

## RESOURCES ON SOIL AND LAND MANAGEMENT OPTIONS

WLE and its partners have developed and contributed to a number of case studies and resources on soil and land management options that can be of use for practitioners: A Soil Best Bets Compendium provides detailed practices, methods and technologies that can be used to maintain or increase the organic matter and fertility of soils. The compendium includes an overview of each ‘best bet’ and its suitability for different geographies and agro-ecologies. A catalogue of exclosure management options provides an overview of management options that can enhance the ecological and economic benefits of exclosures, promote local ownership and support communities to adopt exclosures. It offers knowledge on practices and technologies that can be integrated into exclosure management planning. Finally, the Evaluating Land Management Options (ELMO) tool offers a participatory, user-friendly and gender-sensitive approach for researchers and practitioners to evaluate land management options from farmers’ perspectives.

### Targeting investments in soil organic carbon

Sequestering soil organic carbon (SOC) can help restore soil health and fertility as well as contribute to sustainable and productive agriculture and to climate change mitigation. The 4 pour 1000 Initiative (see Box 2) on soil for food security and climate aspires to sequester approximately 3.5 gigatons of carbon in soils globally each year. Recent analysis shows that agricultural lands could contribute a significant proportion of this goal—between 0.9 and 1.85 gigatons of carbon per year on the 16 million km$^2$ of agricultural land globally suitable for measures to foster carbon sequestration (CIAT 2016).

SOC sequestration has its limits, though: not all soils can be turned into significant SOC sinks, and soils have the potential to sequester carbon only up to the point of equilibrium (Sommer and Bossio 2014). Research in Ethiopia and India highlights the significant variation in SOC stock across different land use types. In Ethiopia, researchers found that the variation in SOC stock between four different land uses (crop, grass, shrub and forest) was significant, ranging from 27.9 g per kg in cropland to 43 g per kg in forestland. Land restoration efforts and land use change (e.g., converting cropland to grassland) can improve SOC levels. However, even when the amount of carbon in the soil has been restored, the soil will tend to lose SOC more quickly than a soil that has never undergone degradation (Abegaz et al. 2016). These findings underscore the need for more research and tools to better target and contextualize interventions to foster SOC sequestration (Milne et al. 2016).

BOX 2. THE 4 POUR 1000 INITIATIVE

Soils for food security and climate, launched at the 2015 United Nations Climate Change Conference (COP 21) in Paris, is a collaboration between CGIAR and French research institutes (L'Institut national de la recherche agronomique (INRA); Le Centre de coopération internationale en recherche agronomique pour le développement (CIRAD); Institut de recherche pour le développement (IRD)). The initiative seeks to mitigate climate change through soil carbon sequestration. Along with the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), WLE is coordinating research on tropical soils to contribute to the target of sequestering 4‰ (four parts per thousand) of carbon in soils per year, as this is the estimated rate needed to mitigate climate change. This work also contributes to the development and implementation of the CGIAR Green Climate Fund initiative. http://4p1000.org/

Monitoring soil carbon content and quality in agricultural systems can help achieve this aim. WLE's Soil Organic Carbon Application calculates the quantity of organic carbon captured in a specific soil profile (tons per ha), based on SOC concentration (g per kg). The application offers a platform for users to visualize the organic carbon content of a soil of their choice, the quantitative impact of soil-conserving practices over time and the magnitude of SOC sequestration if out scaled. The tool allows investors and other decision makers to assess planned efforts to restore degraded land in terms of SOC binding and climate change mitigation. The approach is currently being used to develop global SOC sequestration maps to illustrate where carbon could potentially be sequestered (Zomer et al. in preparation). New low cost tools for measuring soil organic carbon and other soil health attributes using only light (infrared spectroscopy) are allowing integration of soil monitoring into national programs.

## Recovering nutrients from waste and replenishing soils

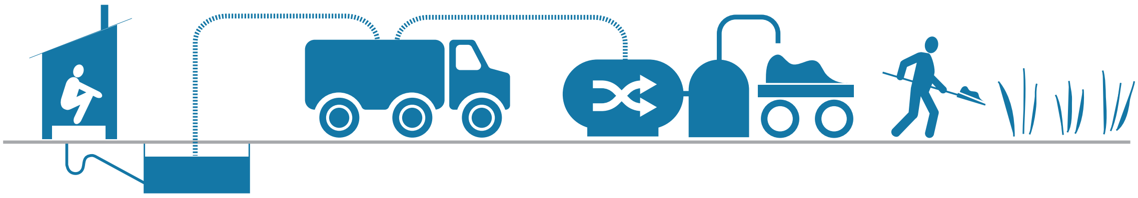
A major driver of soil fertility degradation is continuous cultivation without sufficient replenishment of extracted nutrients. For most smallholders, especially in Africa, fertilizer is prohibitively expensive, even if subsidized and available, and farmers are often not able to bear the risk associated with significant upfront investments (Sommer et al. 2013). Compost and manure are important contributors of crop nutrients and organic matter, positively affecting the characteristics of soils, but the need for processing, transport and labor make it difficult for farmers to obtain and utilize adequate quantities. The export of agricultural produce to urban areas also means a net loss of nutrients from the farming area. These nutrients enter 'waste streams' as excreta and kitchen waste and are thus lost to agriculture. Proper management of domestic and agricultural waste, and efficient resource recovery, provides an opportunity to support a circular economy and bring otherwise 'wasted' nutrients back into the agricultural production cycle (Fig. 1).

One promising option is co-composting, a process through which organic waste streams—such as municipal solid waste, excreta, bio-solids from the sanitation sector and manure from livestock production—are converted into nutrient-rich fertilizer. WLE has explored the technical feasibility and key institutional constraints through a review of 200 case studies across Asia, Africa and Latin America. The research has resulted in a set of promising business models for the safe reuse of human waste, and it is influencing national policies and programs, such as Ghana's fertilizer subsidy program and a new pelletized compost, *Fortifer* ™, which has been approved for commercial use (Rao et al. 2016; Cofie et al. 2016). In May 2017, a public-private partnership launched a co-composting plant designed to produce *Fortifer* ™ in Tema, Ghana (IWMI 2017). In India, the added value of vermicompost is also increasingly recognized by NGOs who are promoting its use to smallholders to improve soil fertility and crop production (Birnholz et al. 2017).

## Planning and monitoring restoration interventions

Information about soil health and degradation is critical for landscape management. Without this knowledge, it is nearly impossible to make smart choices, especially across larger landscape and time scales. WLE developed a land health surveillance framework, based on scientific principles used in public health surveillance (Shepherd et al. 2015). A key insight from applying surveillance principles is the potential for preventive approaches, which reduce

FIG. 1. SUSTAINABLE SANITATION VALUE CHAIN



STAGE I
Access to toilet systems, capture and storage of fecal sludge

STAGE II
Collection, storage and transport

STAGE III
Treatment and conversion of fecal sludge into valuable resource for agricultural use

*Source:* Adapted from an illustration by the Bill & Melinda Gates Foundation: available at https://commons.wikimedia.org/wiki/File:Sanitation_Value_Chain.jpg (accessed on June 20, 2017).

the levels of key risk factors for land degradation, rather than focusing on restoring land that is already degraded. During the past four years, the land health surveillance approach has been applied in Côte d'Ivoire, Cameroon, Chad, Ethiopia, Kenya and Malawi, and it is currently used by the Africa Soil Information Service (AfSIS) (see Box 3). In addition, researchers developed a risk-based approach to evaluating land, water and other development interventions in terms of their probability of success, providing decision makers with further insights on which interventions may work where (Shepherd et al. 2015; Luedeling and Shepherd 2016).

BOX 3. AFRICA SOIL INFORMATION SERVICE

The Africa Soil Information Service (AfSIS) was launched in 2008 and has built the most comprehensive soil sample database available for Africa, with over 28,000 sampling locations. Through AfSIS, WLE has set up soil-plant spectral diagnostic labs in ten African countries and is collaborating with scientists in Ethiopia, Ghana, Nigeria and Tanzania to prepare soil health baselines. The work is also contributing to the development of digital soil property maps for sub-Saharan Africa, which provide spatial predictions of soil properties such as SOC, pH, nutrient content and texture (Hengl et al. 2015). The tools are being used by donors and government agencies in Africa to map soil fertility problems, target soil conservation efforts and measure soil carbon stocks, including by the Ethiopia Soil Information System (EthioSIS), Ghana Soil Information Service (GhaSIS) and Tanzania Soil Information Service (TanSIS).

## CONCLUSION

The prevalence of soil and land degradation, estimated to affect some 23% of land under human use, requires significant action both to predict and prevent degradation, and to restore soil quality. Such measures will contribute to agricultural productivity, food security and climate change mitigation. Interventions in Ethiopia for example have been shown to double crop productivity and halve the risk of crop failure due to moisture stress in some locations. However, the success of interventions depends on selecting the right solutions for the context, including the institutional and social environment, providing incentives and removing institutional barriers. Tools developed by WLE to aid that selection process include the Soil Best Bets Compendium to improve soil fertility; a catalogue of exclosure management options; the participatory ELMO tool; a set of business models around safe reuse of human waste; and a land health surveillance framework. Further research is needed on opportunities to enhance soil organic carbon sequestration; and WLE's protocols for soil monitoring and its ongoing development of SOC sequestration maps are helping to fill this gap. Together this suite of tools is already proving to be a valuable resource for governments and national agriculture organizations to enhance the identification and targeting of appropriate soil and land management interventions.

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WLE's series of Towards Sustainable Intensification: Insights and Solutions Briefs synthesizes the research findings and solutions generated during the program's first phase, which was composed of more than 140 projects across 48 countries in Africa, Asia and Latin America. Each brief is focused on a topic of strategic relevance to sustainable intensification of agriculture and provides analysis of and recommendations on how to place sustainability at the heart of agri-food systems. The series aims to guide and support decision and policy makers, investors, and others working to achieve poverty alleviation and livelihood improvements through sustainable intensification of agriculture.

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