HARVESTING TOMORROW:

ADVANCING SUSTAINABLE LAND MANAGEMENT FOR SOIL FERTILITY

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List of Acronyms and Abbreviations

B	Boron
BMZ	Federal Ministry for Economic Cooperation and Development, Germany Bundesministerium für wirtschaftliche Entwicklung und Zusammenarbeit
Ca	Calcium
CEC	Cation exchange capacity
Cl	Chlorine
Co	Cobalt
COVID-19	Corona virus disease
Cu	Copper
DAP	Diammonium phosphate
EA	Exchangeable acidity
EU	European Union
FREG	Farmers research and extension group
GDP	Gross domestic product
GHG	Greenhouse gas emissions
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Ha	Hectar
IITA	International Institute of Tropical Agriculture
ISFM	Integrated soil fertility management
K	Potassium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
NGO	Non-governmental organisation
NH_4^+	Ammonium
Ni	Nickel
NO_3^-	Nitrate
P	Phosphorus
ProSoil	Global Programme Soil Protection and Rehabilitation for Food Security
S	Sulfur
SLM	Sustainable land management
SOC	Soil organic carbon
SOM	Soil organic matter
TN	Total nitrogen
UNCCD	United Nations Convention to Combat Desertification
WOCAT	World Overview of Conservation Approaches and Technologies

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Acknowledgements

We express our gratitude for the invaluable contributions of the farmers who are actively implementing sustainable land management (SLM) technologies and approaches. Their efforts are instrumental in disseminating knowledge of SLM practices, promoting sustainable soil use, facilitating the rehabilitation of degraded soils, and contributing to sustainable food and agricultural systems.

We would like to thank all agricultural consultants, governmental institutions, public and private sectors, and civil society organisations collaborating in efforts to enhance the sustainability of food and agricultural systems.

Foreword

Bernard Vanlauwe, Deputy Director General for Research for Development, International Institute of Tropical Agriculture (IITA)

Bernard Vanlauwe is the Deputy Director General for Research for Development of the International Institute of Tropical Agriculture (IITA). He joined IITA in Kenya in 2012 to lead the Central Africa hub and the Natural Resource Management research area. He obtained his PhD in 1996 in Applied Biological Sciences from the Catholic University of Leuven, Belgium and has published over 200 papers in scientific journals. He is currently leading the Excellence in Agronomy Initiative of the CGIAR. His main research has focused on the development and scaling of Integrated Soil Fertility Management options for smallholder farmers in key farming systems of sub-Saharan Africa.

The recent global fertiliser crisis has unveiled the precarious state of our agri-food systems, heavily reliant on conventional fertiliser inputs. This crisis exposes vulnerabilities stemming from overdependence on specific sources, fluctuating prices and environmental concerns. Yet, it also serves as a catalyst for exploring and scaling innovative solutions that promote soil health, optimise fertiliser use and enhance farm productivity. This publication embodies that collective action.

Integrated soil fertility management (ISFM) stands at the forefront of our efforts to address these challenges. Defined as a set of practices involving fertilisers, organic inputs and improved germplasm, ISFM empowers farmers to adapt to their local contexts and maximise nutrient use efficiency, ultimately aiming for sustainable crop productivity. This publication focuses specifically on innovative solutions related to fertilisers and other soil amendments, showcasing the progress made by diverse initiatives working within this framework.

The upcoming Africa Fertilizer and Soil Health Summit (AFSHS) presents a significant opportunity to turn the tide on the current crisis. This platform for strategic investments holds the potential to shape the future of fertiliser utilisation and soil health management. It is crucial for the fertiliser and soil health community to actively engage in this summit, ensuring that crucial decisions prioritise sustainable and accessible solutions for farmers worldwide.

Optimising solutions and tackling emerging challenges effectively requires a united front within the fertiliser and soil health community. This necessitates increased collaboration across various research institutions, development organisations and stakeholders. By facilitating knowledge-sharing platforms and fostering joint endeavours, we can amplify our impact and accelerate the development of innovative solutions. Building a strong and organised community is vital for navigating the dynamic landscape of soil fertility management and ensuring long-term agricultural sustainability.

This publication provides evidence to our collective commitment to addressing the global fertiliser crisis. By embracing ISFM principles, advocating for sustainable investments at the upcoming summit and fostering collaboration within the community, we can chart a path towards a future where healthy soils, optimised fertiliser use, and food security go hand in hand.

About

Germany's Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, BMZ) has made significant investments in sustainable land and soil management as well as adaptation to climate change and exploring co-benefits with carbon sequestration in Africa and India. The Global Programme Soil Protection and Rehabilitation for Food Security (ProSoil) is part of BMZ's special initiative Transformation of Agriculture and Food Systems, implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, is a Consortium Partner of the World Overview of Conservation Approaches and Technologies (WOCAT). ProSoil supports smallholder farmers in Benin, Burkina Faso, Ethiopia, India, Kenya, Madagascar and Tunisia through training and capacity building in sustainable land management (SLM) and has promoted the adoption of SLM practices in its partner countries. The programme collaborates with local governments, and public and private sectors in the advancement of sustainable food and agricultural systems. The European Union (EU) is co-funding the programme's work in the field of agroecology in Kenya, Ethiopia, Madagascar and Benin. Another co-funder is the Bill & Melinda Gates Foundation in Ethiopia.

WOCAT is the global network on sustainable land management (SLM) that promotes the documentation, sharing, and use of information and knowledge to support adaptation, innovation, and decision-making in SLM. WOCAT supports governments and their development partners in effective knowledge management and decision-support tools and processes. WOCAT's Consortium Partner, the Alliance of Biodiversity International and the International Center for Tropical Agriculture, supported the coordination and collection of SLM practices in partner countries where ProSoil is deployed.

This compilation consists of ten selected SLM practices that contribute to improved soil fertility and enhance soil health for the sustainability of food and agricultural systems.

Introduction

Soil fertility refers to the ability of soil to provide essential nutrients and a conducive environment for plant growth and development. The various physical, chemical and biological properties of soil contribute to its capacity to support healthy and productive plant life. Key factors of soil fertility are pH balance, organic matter content, microbial activity, biological diversity, soil structure and texture. Fertile soil contains an adequate supply of essential nutrients, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S),[1] among others (Table 1). These nutrients are vital for plant metabolic processes, growth and overall health.

Figure 1: The three pillars of soil fertility[1]

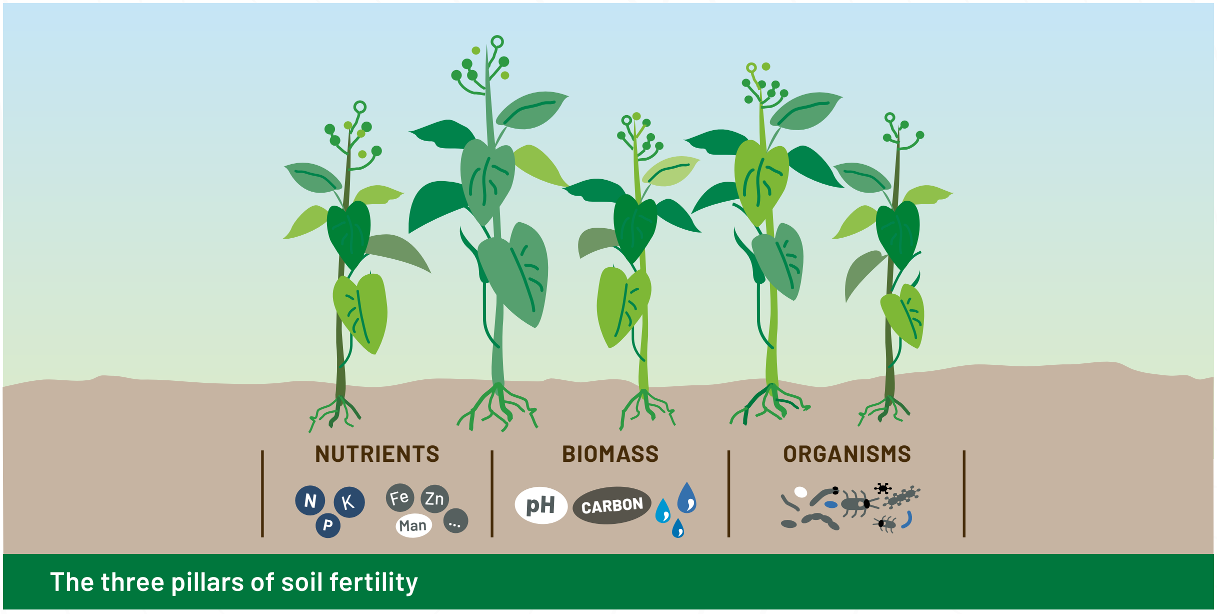

Table 1: Soil nutrients[2]

Primary macronutrients	Secondary macronutrients	Micronutrients	
Nitrogen (N)	Calcium (Ca)	Iron (Fe)	Manganese (Mn)
Phosphorus (P)	Magnesium (Mg)	Copper (Cu)	Boron (B)
Potassium (K)	Sulfur (S)	Zinc (Zn)	Cobalt (Co)
		Chlorine (Cl)	Nickel (Ni)
		Molybdenum (Mo)	

[1] Humberto Blanco and Rattan Lal. "Soil Fertility Management." In Soil Conservation and Management, ed. Humberto Blanco and Rattan Lal Cham: Springer Nature Switzerland, (2023): 363–90. https://doi.org/10.1007/978-3-031-30341-8_15.

[2] IASET. "The Impact of Secondary Macro Nutrients on Crop Production." SSRN Scholarly Paper. Rochester, NY, (June 1, 2021). https://doi.org/10.2139/ssrn.3962862.

Soil pH, the measure of soil acidity or alkalinity, play a crucial role in nutrient availability and microbial activity. Most plants thrive in soils with a pH level between 5.5 and 6.5,[3] however, optimal pH requirements vary among different plant species. Soil organic matter (SOM), derived from plant and animal residues, is a vital component of fertile soil. It provides a source of nutrients for plants,[1] improves soil structure, enhances water retention and supports beneficial soil microorganisms. Soil hosts a diverse community of microorganisms, including bacteria, fungi, protozoa and nematodes, which play crucial roles in nutrient cycling.[3] Alongside associated microbial populations, plant species further enhance nutrient cycling, decomposition, pest and disease control, and overall soil health. Lastly, physical properties of soil, including its texture, structure and porosity influence aeration, root penetration and water movement. They contribute to nutrient and water retention and therefore affect the movement and availability of nutrients for plant uptake.

Soil fertility is the foundation of sustainable and resilient food and agricultural systems. Globally, these systems are under threat with implications on soil health, agricultural productivity, food security, livelihoods and environmental sustainability. One of the major threats is land/soil degradation, which involves the deterioration of soil quality due to erosion, compaction, salinisation, nutrient depletion, and loss of organic matter. According to a report of the United Nation Convention to Combat Desertification (UNCCD) in 2022, up to 40 per cent of global land is degraded,[4] having implications on all living organisms. As soil accounts for 95 per cent of global food production and is a source for 15 of the 18 essential nutrients,[5] its degradation threatens the productivity of agricultural lands, exacerbating hunger and malnutrition. Studies indicate that 24 billion tonnes of fertile top soil is lost annually due to soil erosion, impacting 1.5 billion people[6,7] – a number likely to increase by 135 million by 2045[7] with business as usual.

Core to soil degradation and particularly soil fertility degradation are intensive agricultural practices.[6,7] Unsustainable agricultural practices, such as deforestation and land clearing, overgrazing, monocropping and excessive tillage, have exacerbated nutrient depletion, especially for N, P and K. Additionally, improper application of synthetic fertilisers has further exacerbated this issue, contributing to the decoupling of nutrient cycles, soil acidification and environmental pollution. Synthetic fertiliser consumption has risen sharply, with global consumption reaching 195.38 million tonnes in 2021 from 46.3 million tonnes in 1965 with more nitrogen fertilisers used.[8] While synthetic fertilisers have played a crucial role in increasing agricultural productivity, their indiscriminate and inaccurate use has led to adverse environmental impacts, including nutrient run-off, water pollution and greenhouse gas emissions (GHG). Overapplication of fertilisers contributes to water pollution[9] through run-off and leaching, enhancing waste. This causes eutrophication of water bodies, loss of biodiversity, and disruption of ecosystems. On the other hand, under-application, poor timing and wrong fertiliser use may result in nutrient imbalances/deficiencies, soil acidification, salinisation aggravating soil degradation and poor crop productivity.

Synthetic fertilisers are facing increasing scrutiny due to potential risks associated with their production and use. Another concern revolves around price shocks, where the costs of synthetic fertilisers can fluctuate dramatically due to various factors such as changes in demand, disruptions in the supply chain, and shifts

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3 Ansa Javed et al. "Soil Fertility: Factors Affecting Soil Fertility, and Biodiversity Responsible for Soil Fertility." International Journal of Plant, Animal and Environmental Sciences 12, no. 1 (March 31, 2022): 21–33. http://www.fotunejournals.com/soil-fertility-factors-affecting-soil-fertility-and-biodiversity-responsible-for-soil-fertility.html.

4 UNCCD. "Chronic Land Degradation: UN Offers Stark Warnings and Practical Remedies in Global Land Outlook 2." UNCCD, (2022). https://www.unccd.int/news-stories/press-releases/chronic-land-degradation-un-offers-stark-warnings-and-practical.

5 FAO. "World Soil Day 2022: FAO Publishes First Global Report on Black Soils." Newsroom, (2022). https://www.fao.org/newsroom/detail/world-soil-day-2022-fao-global-report-black-soils/en.

6 Gauri Shankar Gupta. "Land Degradation and Challenges of Food Security." ResearchGate, (2019). https://doi.org/10.5539/res.v11n1p63.

7 Akbar Hossain et al. "Agricultural Land Degradation: Processes and Problems Undermining Future Food Security." in Environment, Climate, Plant and Vegetation Growth, ed. Shah Fahad et al. Cham: Springer International Publishing, (2020): 17–61. https://doi.org/10.1007/978-3-030-49732-3_2.

8 Statista. "Global Fertilizer Consumption by Nutrient 1965–2021." Statista, (2023). https://www.statista.com/statistics/438967/fertilizer-consumption-globally-by-nutrient/.

9 Justice Nyamangara et al. "Chapter 5 – The Role of Synthetic Fertilizers in Enhancing Ecosystem Services in Crop Production Systems in Developing Countries." in The Role of Ecosystem Services in Sustainable Food Systems, ed. Leonard Rusinamhodzi. Academic Press, (2020): 95-117. https://doi.org/10.1016/B978-0-12-816436-5.00005-6.

in energy prices. For instance, the COVID-19 pandemic and the Russian war against Ukraine led to hiked prices of farm inputs including fertilisers and seeds globally.[10] These price fluctuations pose challenges for farmers and agricultural systems reliant on these fertilisers, potentially impacting their affordability and accessibility. Additionally, synthetic fertilisers are predominantly derived from non-renewable resources like natural gas, raising concerns about energy security and the sustainability of their production process.

Global food and agricultural systems are under threat owing to land degradation, soil erosion and soil fertility decline. Climate change further exacerbates these challenges, with extreme weather events and shifting precipitation patterns intensifying soil erosion and nutrient loss. These global fertility issues have far-reaching implications for agricultural productivity and environmental sustainability. Soil degradation and nutrient depletion undermine the capacity of soils to support crop growth, leading to reduced yields, food insecurity and economic losses for farmers. These challenges are particularly of concern in the Global South where agriculture often serves as a primary source of income and sustenance for a large portion of the population. This can perpetuate poverty and food insecurity, particularly in rural areas where access to alternative livelihoods may be limited. Resource-poor smallholder farmers in these countries are most vulnerable to these challenges. For instance, their limited purchasing power hinders the access and use of synthetic fertilisers. For these farmers in many parts of sub-Saharan Africa and South Asia, land degradation coupled with impacts of climate change and variability on production, leads to increased vulnerability to food shortages and economic shocks.

[10] Adithya Sridhar et al. "Global Impact of COVID-19 on Agriculture: Role of Sustainable Agriculture and Digital Farmin." *Environmental Science and Pollution Research* 30, no. 15 (March 1, 2023): 42509–25. https://doi.org/10.1007/s11356-022-19358-w.

Soil Fertility – Sustainable Land Management Nexus

Addressing the challenges of land degradation, soil erosion and soil fertility requires holistic approaches that integrate sustainable land management (SLM) practices, ecosystem restoration efforts, and capacity-building initiatives for smallholder farmers. SLM refers to the use and management of land resources in ways that ensure the long-term productivity and health of ecosystems, while meeting the socioeconomic needs of present and future generations.[11] SLM practices consist of technologies and approaches.[12] They focus on improving soil fertility through conserving SOM, promoting nutrient cycling, and reducing soil erosion and nutrient depletion.

SLM practices can be applied in different ways and means, such as cover cropping, crop rotation, inter cropping, revegetation and agroforestry, that replenish soil nutrients, improve soil structure and enhance water retention capabilities. SLM promotes the use of organic amendments like compost and green manure, enriching SOM and fertility. Additionally, SLM advocates for the responsible use of chemical fertilisers, aiming to minimise environmental harm while maximising nutrient efficiency, ensuring that crops receive essential nutrients without compromising soil health. As part of SLM, soil conservation and physical conservation structures act as erosion control measures, such as contour ploughing and conservation tillage, safeguard against soil degradation and nutrient loss through erosion.

Moreover, SLM practices enhancing soil fertility often involve low-cost or locally available materials and techniques, making them particularly advantageous against the backdrop of self-sufficiency. For instance, practices like composting, mulching and cover cropping utilise organic materials that can be sourced from agricultural waste or livestock manure, reducing the need for expensive external inputs. Techniques such as conservation tillage and agroforestry leverage natural processes and vegetation to improve soil structure and nutrient cycling without requiring significant financial investment. As such, SLM improves soil fertility for improved agricultural productivity, while minimising financial barriers, and improving rural livelihoods and food security. SLM builds soil health and the resilience of agricultural landscapes and rural communities. See also the chapter "Key Challenges to Enhancing Adoption of SLM Practices for Improved Soil Fertility and Health" on page 25.

[11] Wocat. "SLM" Wocat. (Accessed February 22, 2024). https://www.wocat.net/en/slm/.

[12] SLM technology is a physical practice on the land for SLM. An approach is a means of implementing one or more technologies.

Soil Fertility in Ethiopia

Agriculture serves as the backbone of Ethiopia's economy, contributing to about 40 per cent of the country's gross domestic product (GDP) and 80 per cent of exports.[13,14] About 75 per cent of the country's population is employed by the agricultural sector. The agricultural sector is dominated by smallholder farmers, who produce 95 per cent of the main crops grown in the country.[15] Soil fertility is thus paramount for sustaining livelihoods, ensuring food security and driving economic development. The country's agricultural sector faces numerous soil-related problems such as erosion, nutrient depletion and soil degradation. About 40 per cent of Ethiopia's agricultural land is degraded.[15] Continuous cultivation without adequate soil conservation measures has led to erosion, particularly in the highlands, where steep slopes are vulnerable to erosion by rainfall. As a result, valuable topsoil, rich in nutrients and organic matter, is lost, degrading soil fertility and compromising the productivity of agricultural lands, on which smallholder farmers rely on for food and income.

Soil fertility depletion in Ethiopia[16] significantly affects rural livelihoods, with high poverty levels observed due to primary dependence on agriculture.[13] Declining soil fertility reduces crop yields, limiting food production and exacerbating food insecurity in rural communities where a significant portion of the population already faces hunger and malnutrition. 40 to 50 per cent of the Ethiopian population and over 40 per cent of the farming households are food insecure.[17] The status of food security has further been compromised by soil degradation, contributing to environmental degradation, including deforestation, loss of biodiversity and increased vulnerability to climate change impacts such as droughts and floods.[15] These environmental challenges further strain the capacity of rural communities to sustain their livelihoods and adapt to changing climatic conditions, perpetuating a cycle of poverty and environmental degradation.

To boost food production and security, the use of synthetic fertilisers, especially for cereal production in Ethiopia, is increasing. However, the high costs of purchasing limit their use, and improper application of fertilisers limits their effectiveness. A significant percentage of the 60 per cent of farming households that use fertilisers under-apply[16], and the mix of synthetic fertilisers does often not correspond to local contexts with regard to specific soil and crop needs. Optimal application of fertilisers as well as addressing the various aspects surrounding soil fertility is needed.

The pressure on food and agricultural systems is bound to increase considerably owing to the large and growing population, estimated at about 123 million in 2022.[18] More investments in soil health are needed. ProSoil Ethiopia promotes soil fertility through the adoption of SLM practices in the context of ISFM to secure food security and improve the livelihoods of smallholder farmers.

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[13] Komikouma Apelike Wobuibe Neglo, Tnsue Gebrekidan and Kaiyu Lyu. "The Role of Agriculture and Non-Farm Economy in Addressing Food Insecurity in Ethiopia: A Review." Sustainability 13, no. 7 (January 2021): 3874. https://doi.org/10.3390/su13073874.

[14] USAID. "Agriculture and Food Security | Ethiopia." U.S. Agency for International Development (April 27, 2023). https://www.usaid.gov/ethiopia/agriculture-and-food-security.

[15] Gebeyanesh Zerssa et al. "Challenges of Smallholder Farming in Ethiopia and Opportunities by Adopting Climate-Smart Agriculture." *Agriculture* 11, no. 3 (March 2021): 192, https://doi.org/10.3390/agriculture11030192.

[16] Tilahun Gisila Abebe et al. "Growing Use and Impacts of Chemical Fertilizers and Assessing Alternative Organic Fertilizer Sources in Ethiopia." *Applied and Environmental Soil Science* 2022 (March 20, 2022): e4738416. https://doi.org/10.1155/2022/4738416.

[17] Till Stellmacher and Girma Kelboro. "Family Farms, Agricultural Productivity, and the Terrain of Food (In)Security in Ethiopia." *Sustainability* 11, no. 18 (January 2019): 4981. https://doi.org/10.3390/su11184981.

[18] World Bank. "Ethiopia: Overview." World Bank. (Accessed February 22, 2024). https://www.worldbank.org/en/country/ethiopia/overview.

Livestock urine collection and use

Smallholder farmers with livestock, including cattle, sheep and goats, collect and use livestock urine as a substitute for urea fertiliser and for pest control.

Livestock urine collection chamber, storage jerrycan and locally made spraying tool. Bursa District, Sidama Regional State, Ethiopia.

More to know:

Learn more about how ***livestock urine*** can be used as a substitute for urea fertiliser and for pest control on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

Livestock stalls are constructed adjacent to the house with sloping bamboo or stone floors. The sloping floor drains urine into a collection chamber through conduit pipes, where the urine can be stored for up to fifteen days before use. To prevent losses through leaching and volatilisation, the collection chambers are lined with plastic materials and shaded. Construction of the collection unit is done using locally available materials. In cases where collection chambers are not used, the farmers channel the livestock urine to nearby crop plots. The organic amendment is used as foliar or basal fertiliser for different crops such as enset (false banana), maize, barley and vegetables.

Livestock urine has been utilised in traditional agricultural systems for crop protection and soil fertility management. Cattle, sheep, goats, horses, pigs and poultry produce urine with potential use in nutrient cycling and pest control. Used mostly as a nitrogenous fertiliser, cow urine contains 2.5 per cent urea and has other elements including potassium, phosphorus, calcium, magnesium, chlorine, sulfur and water.[19] Moreover, the presence of sodium, chlorine, sulfur, manganese, iron and enzymes in cow urine makes it suitable for pest management.[20] Livestock urine may be used in different concentrations and with other formulations for improved efficacy. Livestock urine improves soil structure and texture and increases organic carbon, available N, P, K, and exchangeable Ca and Mg.[19] With a significant amount of N, urea in the urine transforms to available forms for plant uptake. It undergoes mineralisation into ammonium (NH_4^+), which may subsequently undergo nitrification into nitrate (NO_3^-). A study in India recorded better yields in cowpeas attributed to effective control of insects (pests), such as thrips, aphids, and jassids, using different formulations and concentrations of cow urine (Table 2).[21]

[19] Swati Pradhan et al. "Bio-Efficacy of Cow Urine on Crop Production: A Review." (January 1, 2018). 298–301.

[20] M. Devasena and V. Sangeetha. "Chapter Eleven – Cow Urine: Potential Resource for Sustainable Agriculture." in *Emerging Issues in Climate Smart Livestock Production*, ed. Sukanta Mondal and Ram Lakhan Singh (Academic Press, 2022), 247–62. https://doi.org/10.1016/B978-0-12-822265-2.00007-7.

[21] CC Patel et al. "Bioefficacy of Cow Urine and Different Types of Bio-Pesticide against Sucking Insect Pests of Cowpea." (2019). *International Journal of Chemical Studies* 7, no. 3 (2019): 4664-4667.

Table 2: Cow urine formulations and concentrations for control of thrips, aphids and jassids in cowpea: Impact on yield[21]

Use of cow urine and other amendments	Yield in kg/ha
100% cow urine	673 kg/ha
75% cow urine	641 kg/ha
100% cow urine + 1% neem oil	698 kg/ha
100% cow urine + 5% neem seed kernel extract	684 kg/ha
50% cow urine + 1% neem oil	666 kg/ha
50% cow urine + 5% neem seed kernel extract	656 kg/ha
Control	**448 kg/ha**

Source: Created by the authors

Despite its use as biofertiliser and biopesticide, livestock urine has the potential to cause nutrient imbalances. While N is crucial for plant growth, excessive N can lead to environmental challenges such as NO_3^- leaching into groundwater or runoff into nearby water bodies, contributing to eutrophication. The NO_3^- may also undergo denitrification into gaseous forms such as nitrous oxide and nitric oxide enhancing the losses. To address this, ProSoil farmers line and cover the urine collection chambers and receive extensive extension services for balanced application. The application of SLM practices should be supported by being paired with extension services, sensitisation approaches and community involvement.

Bioslurry

Bioslurry refers to the nutrient-rich liquid residue produced from anaerobic digestion of organic materials, typically animal manure or organic waste.

A farmer composting and drying bioslurry for use in remote farmland. Adale-Bise Kebele, Mattu District.

More to know:

Learn more about how ***bioslurry*** refers to the nutrient-rich liquid residue produced from anaerobic digestion on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

Anaerobic digestion is a biological process where microorganisms break down organic matter in the absence of oxygen, resulting in the production of biogas (mainly methane and carbon dioxide) and a nutrient-rich slurry, bioslurry, as waste. The liquid form of bioslurry is mostly applied to crops within the homestead using water cans or buckets. Dried bioslurry may be transported to fields. Row application is done to vegetables and perennial crops once during the growing season to boost soil fertility. ProSoil farmers have reported a decrease in the use of synthetic fertilisers. In addition, reduced populations of fall armyworm and maize stalk borer have been observed with bioslurry use. Bioslurry can control tobacco mosaic disease; this pesticidal effect could be attributed to the formation of organophosphates and carbamates dependent on the environment and composition of bioslurry.[22]

Bioslurry facilitates nutrient recycling as it contains nutrients that can be returned to the soil, closing the nutrient loop and reducing the dependence on synthetic fertilisers. The application of bioslurry to crop fields is a common practice in Ethiopia,[23,24] with or without the use of synthetic fertilisers. In the cultivation of tomato (*Solanum lycopersicum Mill.*) in Ethiopia's Addis Ababa, application of liquid bioslurry yielded more total N (TN), soil organic carbon (SOC) and soil moisture, and increased porosity with reduced bulk density compared to chemical fertiliser (Table 3).[25] The SOC improves soil structure, moisture retention, nutrient availability and creates favourable conditions for microbial growth and activity. The increased porosity implies enhanced infiltration which contributes to run-off and soil erosion control. Moreover, improved soil chemical and physical parameters contributed to improved crop productivity. A study in

[22] Bakari Chaka et al. "Optimization of Anti-Microbial and Pesticidal Efficacies of Bio-Slurry Using Terminalia b. and Acanthaceae Spp. Extracts." *International Journal of Research and Innovation in Applied Science* 4, no. 12 (2019). https://www.rsisinternational.org/journals/ijrias/DigitalLibrary/Vol.4&Issue12/31-41.pdf.

[23] Biramo Geremew, Girma Jibat, and Birhanu Biazin. "Effects of Dry Bioslurry and Chemical Fertilizers on Tomato Growth Performance, Fruit Yield and Soil Properties under Irrigated Condition in Southern Ethiopian." *African Journal of Agricultural Research* 14 (October 31, 2019): 1685–92. https://doi.org/10.5897/AJAR2019.14372.

[24] Tsehay Kebede et al. "Effect of Bioslurry and Chemical Fertilizer on the Agronomic Performances of Maize." Heliyon 9, no. 1 (January 2023): e13000, https://doi.org/10.1016/j.heliyon.2023.e13000.

[25] Tseganesh Lolamo et al. "Effects of Bio-Slurry and Chemical Fertilizer Application on Soil Properties and Food Safety of Tomato (*Solanum Lycopersicum* Mill.)." *Applied and Environmental Soil Science* 2023 (March 20, 2023): e6694536. https://doi.org/10.1155/2023/6694536.

Southern Ethiopia recommended integration of dried bioslurry with N and P fertiliser or blended fertiliser for better yields in tomatoes.[23] Another study further recorded highest maize yields in the Sidam region of Ethiopia under 25 per cent bioslurry combined with chemical fertiliser (Table 4).

Table 3: Effect of bioslurry and chemical fertiliser application on soil properties under tomato cultivation in Ethiopia[25]

Soil parameter	Bioslurry	Chemical fertiliser
Total N (%)	0.26	0.24
SOC (%)	2.98	2.5
Moisture (%)	37	15.4
Porosity (%)	70	62.1
Bulk density (g cm^{-3})	0.83	1
CEC (cmol kg^{-1})	29	23.6
Ca (cmol kg^{-1})	28	22.2
Na (cmol kg^{-1})	0.23	0.2
K (cmol kg^{-1})	2.7	2.18

Source: Created by the authors

Table 4: Effect of bioslurry and chemical fertiliser application on maize yields in Ethiopia[24]

Treatment	Grain yield (t ha^{-1})
100% bioslurry	5.87
75% bioslurry + 25% chemical fertiliser	6.35
50% bioslurry + 50% chemical fertiliser	6.84
25% bioslurry + 75% chemical fertiliser	7.09
100% chemical fertiliser	6.67

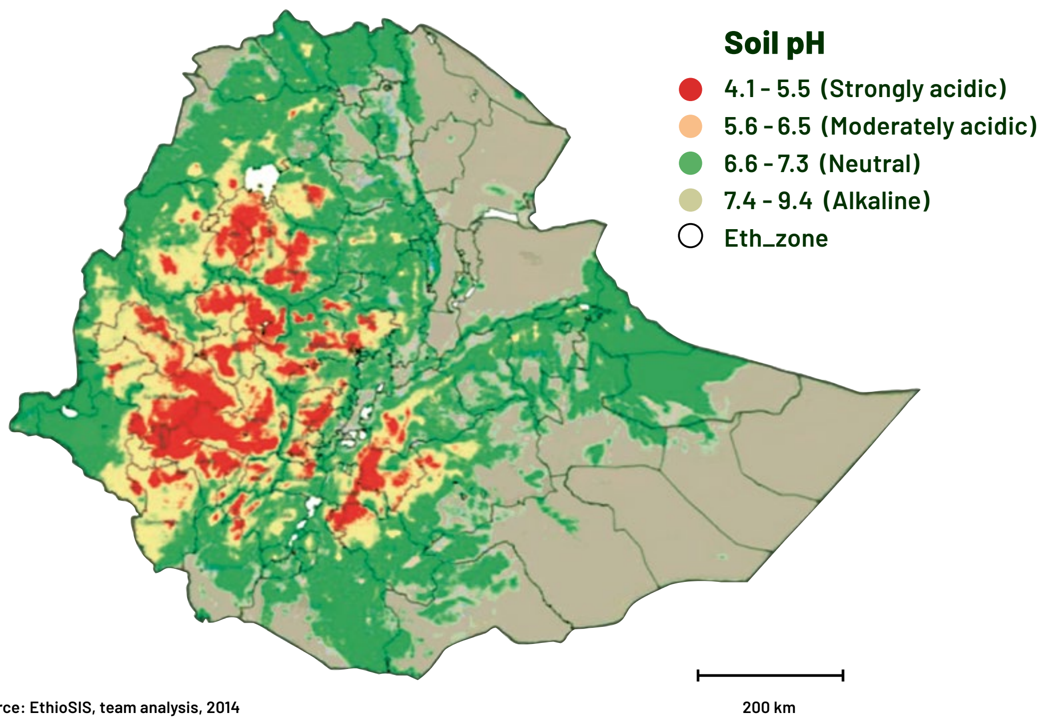
Source: Created by the authors

Treating acid soils with lime

Soil acidification is one of the main forms of land degradation in Ethiopia. About 41 per cent of cultivated lands in the country are affected by soil acidity, 28 per cent being moderate to weak acidic (pH 5.8 to 6.7) and 13 per cent being strong to moderate acidic (pH less than 5.5).[26] 3.5 million hectares, accounting for 28 per cent of cultivated land, are highly acidic,[27,28] with land abandonment and migration attributed to extreme acidity.[28] Acidification results from the build-up of hydrogen ions (H^+) in the soil. This is particularly common in Ethiopian highlands where leaching is prevalent, leading to the leaching of basic ions like calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+).[29] While acidification may occur naturally[29] due to weathering of rocks or minerals, unsustainable agricultural practices such as slash-and-burn farming and deforestation accelerate the process by creating favourable conditions for soil erosion and nutrient leaching. Moreover, the continuous application of acidic fertilisers, such as urea and DAP (diammonium phosphate), and intensive monocropping as well as reside removal potentially enhance soil acidification.[30]

Extend of soil acidity in Ethiopia

>80% of the landmasses originating from Nitisols are acidic



Source: EthioSIS, team analysis, 2014

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[26] Wegene Negese. "Review on the Extent of Acid Soil in Ethiopia, Its Impact and Management Methods." *Journal of Natural Sciences Research* 9 (May 19, 2021): 24–36.

[27] Agegnehu Getachew, Yirga Chilot, and James Warner "Soil Acidity in Ethiopia, Cause, Effects, Management and Policy Consideration." IFPRI, EIAR (2018). https://oar.icrisat.org/11409/1/Managing%20acid%20soils_Ethiopia_02%20May%202019_low.pdf

[28] Tilahun Amede et al. "Managing Acid Soils for Reclaiming Livelihoods in Ethiopia." (2019) ICRISAT-GIZ, Addis Ababa. https://hdl.handle.net/10568/101619.

[29] Fanuel Laekemariam and Kibebew Kibret. "Extent, Distribution, and Causes of Soil Acidity under Subsistence Farming System and Lime Recommendation: The Case in Wolaita, Southern Ethiopia." *Applied and Environmental Soil Science* 2021 (September 26, 2021): e5556563. https://doi.org/10.1155/2021/5556563.

[30] Bikila Takala. "Soil Acidity and Its Management Options in Western Ethiopia: Review." *Environmental Earth Sciences* Vol.9 (October 31, 2019): 27-35. https://doi.org/10.7176/JEES/9-10-04.

What are the benefits

Increased yield
(In cereals)

30-40 %
increase with liming alone

50-100 %
increase when combined with ISFM

Healthier soils and crops

Increased **nutrient availability**

Improved **grain quality**

Improved soil **microbial activity**

Reduced **fertilizer costs**

Decreased Aluminum and Magnesium **toxicity**

Greater **pesticide effectiveness**

Did you know? **9 billion birr*** per year is lost in foregone wheat production.

Source: 1. Getachew Agegnehu et al. 2018; 2. James Warner et al. 2018

*1 birr = 0.035 USD

Soil acidification is associated with aluminium (Al^{3+}) and manganese (Mn^{2+}) toxicities which limit the availability and uptake of nutrients such as N, P, K, Ca, Mg and Mo.[26,30] Al^{3+} toxicity inhibits root growth by injuring the apex and limiting root elongation;[26] it further inhibits shoot growth.[30] As a result, soil acidity impedes plant growth with the potential of reduced crop yields. ProSoil advocates for liming soils with a pH level below 5.Liming raises soil pH and creates favourable conditions for crop growth. It reduces Al^{3+} and Mn^{2+} toxicity, increasing Ca and Mg supplies and enhancing the availability of nutrients. Additionally, raising pH potentially creates favourable conditions for microbial activity, important for nutrient cycling and organic matter decomposition.[26,30] A study in the Southern Ethiopia highlands recorded increased pH, available P, and TN with application of lime, resulting in 46 per cent and 30 per cent higher total biomass and grain yields in barley compared to lack of liming.[31] Another study in Northwestern Ethiopia observed a decreasing trend in exchangeable acidity (EA) with an increasing liming rate (Table 5).[32] The liming rate affects the soil status and crop productivity. ProSoil farmers are advised to apply four or more tonnes per hectare. Application is done by a limited number of farmers due to the relatively high cost (determined by the rate after soil testing) and poor supply of lime. Those farmers have observed positive effects on crop productivity from the second cropping season.

More to know:

Learn more about how *ProSoil* advocates for liming soils with a pH level below 5 on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

[31] Getahun Haile et al. "Soil Properties, Crop Yield, and Economic Return in Response to Lime Application on Acidic Nitisols of Southern Highlands of Ethiopia." *International Journal of Agronomy* 2023. (December 29, 2023): e6105725. https://doi.org/10.1155/2023/6105725.

[32] Erkihun Alemu, Yihenew G. Selassie, and Birru Yitaferu. "Effect of Lime on Selected Soil Chemical Properties, Maize (Zea Mays L.) Yield and Determination of Rate and Method of Its Application in Northwestern Ethiopia." *Heliyon* 8, no. 1 (January 2022): e08657. https://doi.org/10.1016/j.heliyon.2021.e08657.

Table 5: Liming rate effect on exchangeable acidity (EA) in a maize crop in Ethiopia[32]

Treatment	EA (cmol kg^{-1})
Control without liming	1.939
0.060 t ha^{-1}	2.020
0.120 t ha^{-1}	1.788
0.180 ha^{-1}	0.936
1 t ha^{-1}	0.480
2 t ha^{-1}	0.460
3.5 t ha^{-1}	0.070
4 t ha^{-1}	0.116
7 t ha^{-1}	0.288
14 t ha^{-1}	0.048

Source: Created by the authors

Wheat crops grown on degraded soil with pH 4.94 after treating with lime. Gito kebele, Gechi district.

Integrated Soil Fertility Management (ISFM)

ProSoil's Integrated Soil Fertility Management project (ISFM+) supports the Integrated Soil Fertility Management (ISFM) approach among smallholder farmers.

The approach considers different technologies and agronomic practices that are complementary and adapted to local conditions that enhance soil health and crop productivity. For example, integrating the use of inorganic and organic fertilisers with other agricultural practices such as liming acidic soils, intercropping with legumes and use of improved seeds. ISFM boosts soil fertility and structure resulting in improved crop yields. Its adoption has been associated with maize yield increase by up to 16 per cent and 27 per cent in Kenya and Ghana, respectively.[33] A qualitative study in the Ethiopian highlands (ProSoil regions of Tigray, Oromia and Amhara) established that while the ISFM approach increases labour demand in wheat, teff and maize production, the approach significantly increases crop yields and land productivity.[34] Increased labour requirements result from combining the different technologies during crop production, but pay off at a later stage. The increased crop yields contribute to food availability, especially during harvest, and further boost household incomes. Such has been reported in ProSoil regions of Ahmara and Oromia.[35]

More to know:

Learn more about how the ***Integrated Soil Fertility Management*** supports the approach among smallholder farmers on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

An integral part of ProSoil's ISFM approach is stakeholder engagement including farmers and policy makers at different levels. The Farmers Research and Extension Group (FREG) sub-approach discussed in the next section supports the implementation of ISFM technologies. Additionally, the Soil Fertility Improvement Cluster approach supports the scaling out of the ISFM approach by creating awareness of the technologies. ProSoil, through the ISFM+ project, also provides technical and financial support for capacity building, training, and exposure visits, promoting diffusion and adoption of ISFM. Stakeholder engagement is crucial for the promotion of SLM practices for soil fertility improvement as it considers the perspectives, needs and knowledge of all relevant parties in the decision-making process. Engaging policymakers, farmers and local communities[36] as a strategy under the ISFM approach yields benefits from diverse expertise, local knowledge and social support networks. This involvement helps to foster ownership and commitment to the SLM practices, leading to more effective implementation and long-term sustainability.

[33] Ivan Solomon Adolwa, Stefan Schwarze, and Andreas Buerkert. "Impacts of Integrated Soil Fertility Management on Yield and Household Income: The Case of Tamale (Ghana) and Kakamega (Kenya)." *Ecological Economics* 161 (July 1, 2019): 186–92. https://doi.org/10.1016/j.ecolecon.2019.03.023.

[34] Denise Hörner and Meike Wollni. "Does Integrated Soil Fertility Management Increase Returns to Land and Labor?." *Agricultural Economics* 53, no. 3 (2022): 337–55. https://doi.org/10.1111/agec.12699.

[35] Denise Hörner and Meike Wollni. "Integrated Soil Fertility Management and Household Welfare in Ethiopia." Food Policy 100 (April 1, 2021): 102022. https://doi.org/10.1016/j.foodpol.2020.102022.

[36] Meskerem Abi et al. "Enabling Policy and Institutional Environment for Scaling-Up Sustainable Land Management in Central Highlands of Ethiopia." *Ethiopian Journal of Development Research* 43, no. 1 (2021): 21–50. http://ejol.aau.edu.et/index.php/EJDR/article/view/4265.

Farmers Research and Extension Group (FREG)

Farmers Research and Extension Groups (FREGs) are pivotal in Ethiopia for testing and disseminating best practices in the ISFM+ project and agroecological principles.

A FREG consists of 50 or more people in a *Kebele* (lowest administrative unit in Ethiopia), with three sub-groups of 15 to 17 people in a homogenous landscape. These groups operate on a participatory basis, involving farmers in joint investigation and learning, which enhances the adoption of SLM practices for improved soil fertility and health. FREG members collectively identify soil-related issues, participate in training sessions, and demonstrate various technologies such as cover cropping, intercropping, use of vermicompost and bioslurry, and treatment of acidic soils with lime. Within FREGs, there is a strong emphasis on inclusivity, with one-third of the members being women. This ensures that agricultural knowledge and benefits are accessible to all members of the community, promoting gender equity in farming. Indeed, women inclusion in farmers' groups and active participation in decision-making and production fosters sustainable agriculture.[37]

More to know:

Learn more about how ***Farmers Research and Extension Groups (FREGs)*** are pivotal in Ethiopia on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

Implementation of the FREGs approach also involves the engagement of model farmers, who are proactive members, adopt and demonstrate SLM technologies and act as ambassadors, transferring knowledge and skills to their peers. Model farmers engage the community, reaching out to farmers within and outside the ProSoil programme. Use of model farmers integrates a bottom-up strategy within the usual top-down approach further scaling out SLM practices. This has been reported to increase the coverage of extension and advisory services with enhanced adoption of technologies for improved production and productivity in nearly all farming households in the community.[38]

The FREG approach further relies on demonstration plots, serving as experimental sites for showcasing different technologies and crop types. Furthermore, FREGs organise field days and exchange visits to enhance the dissemination of technologies to encourage learning from one another. The FREGs also receive technical support and advisory services from the *Woreda* (administration unit above *Kebele*) agricultural officers and development agents. This assistance ensures that farmers receive the necessary guidance to overcome challenges and effectively implement SLM practices. Financial and technical support by ProSoil further strengthens the implementation of the practices. Stakeholder engagement and collaboration enhance extension performance, as such, assuring the sustainability of innovative practices for improved soil health and productivity.[39]

[37] Annet A. Mulema et al. "Women Farmers' Participation in the Agricultural Research Process: Implications for Agricultural Sustainability in Ethiopia." *International Journal of Agricultural Sustainability* 17, no. 2 (March 4, 2019): 127–45. https://doi.org/10.1080/14735903.2019.1569578.

[38] Selam Hailemichael and Ruth Haug. "The Use and Abuse of the 'Model Farmer' Approach in Agricultural Extension in Ethiopia." *The Journal of Agricultural Education and Extension* 26, no. 5 (October 19, 2020): 465–84. https://doi.org/10.1080/1389224X.2020.1757475.

[39] Mekonnen Hailu et al. "Understanding Factors Affecting the Performance of Agricultural Extension System in Ethiopia." *Ethiopian Journal of Agricultural Sciences* 30, no. 4 (October 31, 2020): 237–63. https://www.ajol.info/index.php/ejas/article/view/201145.

Soil Fertility in India

Agriculture is the mainstay of the Indian economy, contributing to about 16.5 per cent of the country's GDP, and providing employment to 71 per cent of rural women[40] and 44 per cent of the country's population.[41] It is the mainstay for rural livelihoods and national development. The sector accounts for $400 billion of the country's economy[41], with smallholder and marginal farmers cultivating about 126 million ha of arable land.[40] Soil fertility decline in India is thus a significant threat to food security, rural livelihoods and environmental sustainability. Unsustainable agricultural practices, such as intensive farming practices, excessive use of chemical fertilisers and pesticides, inadequate soil management techniques, deforestation and improper irrigation methods, contribute to the degradation of soil health. As a result, soils across the country are experiencing erosion, loss of organic matter, nutrient depletion, compaction and salinisation, all of which diminish their fertility and productivity

The Green Revolution played a key role in increasing food production in the country, however, the intensified agricultural production through high input of synthetic chemicals resulted in a decline in soil productivity. Eventually, the high concentrations of inorganic fertilisers, insecticides, fungicides, nematicides, herbicides and other pesticides in soil significantly reduced populations and biological activity of beneficial soil microbes.[42] The intensive use of soil depreciated its quality as evidenced by a decline in SOC and nutrient deficiencies and ultimately crop productivity.[43] India is projected to have an urban population of 600 million by 2030.[40] Therefore, there is an urgent need to address this challenge not only for food production but also for environmental conservation. India has recognised this need and is now working towards a natural farming system with an integrated, transformational process towards agroecology.

Smallholder farmers, who form the backbone of the Indian agriculture, are particularly vulnerable to the impacts of soil fertility decline due to limited access to resources and knowledge to address these challenges. ProSoil India promotes the adoption of SLM practices for improved soil health and productivity in the country. This is in line with schemes and programmes promoted by the Government of India working towards Natural Farming and a transformation of agri-food systems.[44]

[40] Ashok Gulati and Ritika Juneja. "Transforming Indian Agriculture." in *Indian Agriculture Towards 2030: Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems*, ed. Ramesh Chand, Pramod Joshi, and Shyam Khadka, India Studies in Business and Economics (Singapore: Springer Nature, 2022), 9–37. https://doi.org/10.1007/978-981-19-0763-0_2.

[41] Anil Singh et al. "Role of Agriculture in Making India $5 Trillion Economy under Corona Pandemic Circumstance." *Journal of AgriSearch* 6 (June 8, 2020). https://doi.org/10.21921/jas.v6i02.18097.

[42] Priyanka Srivastava, Manju Balhara, and Bhoopander Giri. "Soil Health in India: Past History and Future Perspective." in *Soil Health*, ed. Bhoopander Giri and Ajit Varma, Soil Biology (Cham: Springer International Publishing, 2020), 1–19. https://doi.org/10.1007/978-3-030-44364-1_1.

[43] Nirmalendu Basak et al. "Soil Quality and Productivity Improvement: Indian Story." *Proceedings of the Indian National Science Academy* 87, no. 1 (March 1, 2021): 2–10. https://doi.org/10.1007/s43538-021-00007-8.

[44] NITI Aayog. Natural farming. https://naturalfarming.niti.gov.in/.

Biochar application on homestead land

Biochar is a type of charcoal that is made from organic materials like wood, agricultural waste, or even animal manure. It is produced in a process called pyrolysis, which involves heating these materials in a low-oxygen environment. This prevents them from fully combusting and instead turns them into a stable form of carbon. In the preparation of biochar, ProSoil farmers use low-cost kiln units developed by the Indian Council of Agricultural Research Institutions or traditional methods, for instance, digging soil pits and burning organic residue while covering its top with soil. The farmers apply a rate of 10 to 20 t ha^{-1} and have reported a yield increase of 20 to 30 per cent with biochar application.

Biochar application to soil has the potential to improve soil health and fertility. It can increase water retention, nutrient availability[45] and microbial activity, and improve the pH value of acidic soils. This leads to improved crop growth and yields, especially in soils that are depleted or degraded. Biochar itself is low in nutrients and is usually topped up with a nutrient carrier (e.g. compost). The mixture is then called Terra Preta. Biochar is therefore not a fertiliser. If biochar was to be used in large quantities as a soil conditioner, significant amounts of carbon could be sequestered or stored on a global scale. This would help to mitigate global warming.

More to know:

Learn more about how ***biochar*** application can improve soil health and fertility on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

In North-West India, a study recorded increased uptake of N, P and K with biochar application in wheat and cotton irrigated with saline water.[46] The study recorded reduced bulk density and increased infiltration rate after five years of application. The improved soil conditions create favourable conditions for plant growth. The positive effects of biochar application are further enhanced by combining it with other soil amendments. Elsewhere in India (Mandla district) combined application of biochar, farmyard manure, zinc sulfate, and soil test value-based fertilisers significantly increased SOC, available N, P and K in the formerly acidic soil of a rice-cowpea system.[45] Increased SOC is important in climate and soil functionality regulation[47], such as carbon sequestration, water retention and storage, soil structure, microbial activity, and nutrient availability in the long-term. For instance, a study in India recorded negative greenhouse gas emissions with the production and application of Terra Preta Substrate (TPS), attributed to an assumed carbon sequestration exceeding GHG emissions.[48]

Preparation of biochar by the farmers. Mandla, Madhya Pradesh, India

[45] Hari Mohan Meena and H. C. Prakasha. "Effect of Biochar, Lime and Soil Test Value Based Fertilizer Application on Soil Fertility, Nutrient Uptake and Yield of Rice-Cowpea Cropping System in an Acid Soil of Karnataka." *Journal of Plant Nutrition* 43, no. 17 (July 14, 2020): 2664–79. https://doi.org/10.1080/01904167.2020.1793188.

[46] Gurpreet Singh et al. "Rice Straw Biochar Application to Soil Irrigated with Saline Water in a Cotton-Wheat System Improves Crop Performance and Soil Functionality in North-West India." *Journal of Environmental Management* 295 (October 1, 2021): 113277. https://doi.org/10.1016/j.jenvman.2021.113277.

[47] Martin Wiesmeier et al. "Soil Organic Carbon Storage as a Key Function of Soils - A Review of Drivers and Indicators at Various Scales." Geoderma 333 (January 1, 2019): 149–62. https://doi.org/10.1016/j.geoderma.2018.07.026.

[48] Stefan Majer et al. "Greenhouse Gas Emissions from Terra Preta Substrates in India." (GIZ, 2023). https://www.giz.de/en/downloads/giz2023-en-greenhouse-gas-emissions-from-terra-preta-substrates-in-india.pdf.

City compost: a solution for waste management and soil health improvement

ProSoil India has partnered with local municipalities in promoting city composting in India as a sustainable solution to manage organic municipal waste, improve soil health and mitigate environmental issues.

With the rapid urbanisation and population growth,[40] cities in India are facing immense challenges in waste management, particularly organic waste generated from households, markets and industries. Usually, urban authorities collect organic waste from urban areas, process it into certified compost and distribute it via digital tools to farmers as organic material, supplementing traditional farmyard manure. For ease of collection, households, institutions and businesses are encouraged to segregate their organic waste at the source.

City composting diverts organic waste from landfills, reducing the burden on already overstretched waste management infrastructure and mitigating environmental pollution. The compost produced is an organic fertiliser, improving soil health, closing the urban rural nutrient gap, thus increasing agricultural productivity and reducing the dependency on chemical fertilisers. ProSoil farmers have reduced the use of these fertilisers. Compost application has increased TN, available P and total porosity.[49] Another study in the Shiwaliks of the Indian Himalayas recorded a significant increase in available N, enzymatic activities, microbial biomass carbon and microbial quotient with the application of wheat compost and wheat-rice compost.[50] As such, the application of compost improves soil fertility and structure through increased organic matter, enhancing soil moisture retention.

Moreover, city composting initiatives contribute to job creation, by creating opportunities for waste collectors, compost producers and entrepreneurs involved in waste management activities

More to know:

Learn more about how ***city composting*** improves waste management and soil health in India on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

[49] Mayur Shirish Jain and Ajay S. Kalamdhad. "Soil Revitalization via Waste Utilization: Compost Effects on Soil Organic Properties, Nutritional, Sorption and Physical Properties." *Environmental Technology & Innovation* 18 (May 1, 2020): 100668. https://doi.org/10.1016/j.eti.2020.100668.

[50] Richa Rajput et al. "Soil Nutrients, Microbial Biomass, and Crop Response to Organic Amendments in Rice Cropping System in the Shiwaliks of Indian Himalayas." *International Journal of Recycling of Organic Waste in Agriculture* 8, no. 1 (March 1, 2019): 73–85. https://doi.org/10.1007/s40093-018-0230-x.

Soil Fertility in Kenya

Agriculture contributes to about 33 per cent of Kenya's GDP directly and an additional 27 per cent indirectly through linkage with other sectors.[51] It is a pillar for economic growth and supports livelihoods, particularly in rural areas. The sector employs 40 per cent of the country's population and 70 per cent of the rural population.[51] Declining land productivity in Kenya is a core impediment to attaining food security and improving rural livelihoods. At the same time, intensified agricultural activities in the country have significantly contributed to land degradation, enhancing the loss of TN, SOC, magnesium and boron.[52] Salinisation, soil compaction and soil erosion have become common in arable lands. These factors directly or indirectly affect soil health and productivity. The use of synthetic fertilisers increased crop production, however, residual effects of excess or improper use have depreciated soil quality over time. This has been evident with the continuous use of N fertilisers. High fertiliser prices further limit their use especially by smallholder farmers, impeding soil fertility. As the country's population is still increasing, finding sustainable solutions to improve soil fertility and health becomes imperative.

[51] FAO. "Kenya at a Glance | FAO in Kenya | Food and Agriculture Organization of the United Nations." accessed March 10, 2024. https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/.

[52] Daniel Kyalo Willy et al. "The Effect of Land Use Change on Soil Fertility Parameters in Densely Populated Areas of Kenya." *Geoderma* 343 (June 1, 2019): 254–62. https://doi.org/10.1016/j.geoderma.2019.02.033.

Vermicomposting: an effective liquid fertiliser and biopesticide

ProSoil Kenya promotes vermicomposting. Vermicomposting is a process of composting organic waste using worms, typically red wriggler worms (*Eisenia fetida*). These worms consume organic material like kitchen scraps, paper and animal waste, breaking them down into nutrient-rich compost through their digestive process. As a low-cost and maintenance method, smallholder farmers use easily available materials for constructing vermicomposting structures such as wood and drums. Compost is collected every 2.5 to 3 weeks, while vermi juice (leachate) is collected every two months. The vermi juice is used as a foliar fertiliser and pesticide.

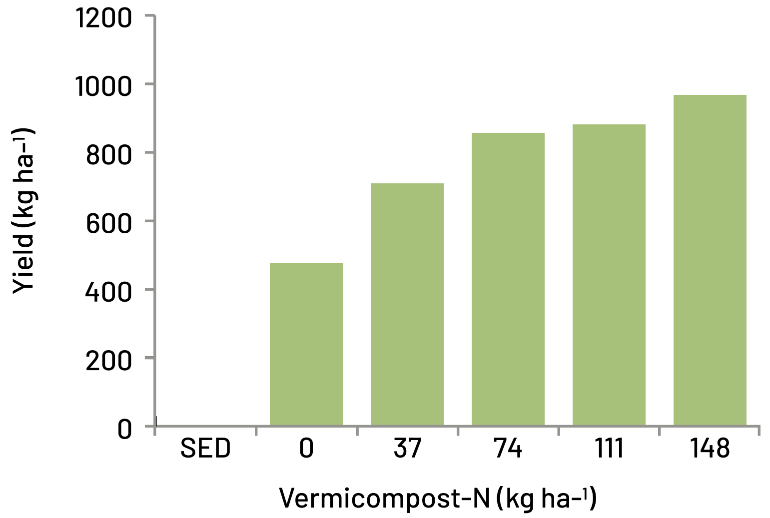
More to know:

Learn more about how ProSoil Kenya promotes ***vermicomposting*** on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

Vermicomposting is effective in enriching the soil with nutrients for crop production. The application of vermicompost compared to urea on soil samples from Siaya County, Kenya, yielded higher nodulation, nodulation occupancy, and N uptake in soybeans.[53] Applying it at different rates of 0, 37, 74, 111 and 148 kg N ha^{-1} resulted in grain yield increases of 475, 709, 856, 880 and 966 kg ha^{-1}, respectively (Figure 1). Additionally, in the University of Embu demonstration farm, Kenya, the application of vermicompost from different sources in tomato crop increased Na, P, K and SOC and reduced EA (Table 6).[54] The reduced EA indicated an increase in soil pH and improved soil conditions for plant growth. As a liquid fertiliser, ProSoil farmers mix vermi juice with water for foliar application. A similar mix can also be used for the control of fall armyworms and aphids, presenting an opportunity for women's economic empowerment through its production, application and distribution. Vermicompost and vermi juice have significant potential to enhance soil conditions and control pests for improved soil health and crop productivity.

Figure 2: Vermicompost application rates effect on soybean grain yields[53]



[53] Catherine Mathenge et al. "Variability of Soybean Response to Rhizobia Inoculant, Vermicompost, and a Legume-Specific Fertilizer Blend in Siaya County of Kenya." *Soil and Tillage Research* 194 (November 1, 2019): 104290. https://doi.org/10.1016/j.still.2019.06.007.

[54] Miriam Ogake Mochache, Rebecca Yegon, and Onesmus Ngetich. "Performance of Vermicomposted Wastes for Tomato (Lycopersicon Esculentum Mill.), Production: A Case Study of Embu, Kenya." October 2021. https://doi.org/10.30486/IJROWA.2021.1904563.1103.

Table 6: Effect of vermicompost on soil properties[54]

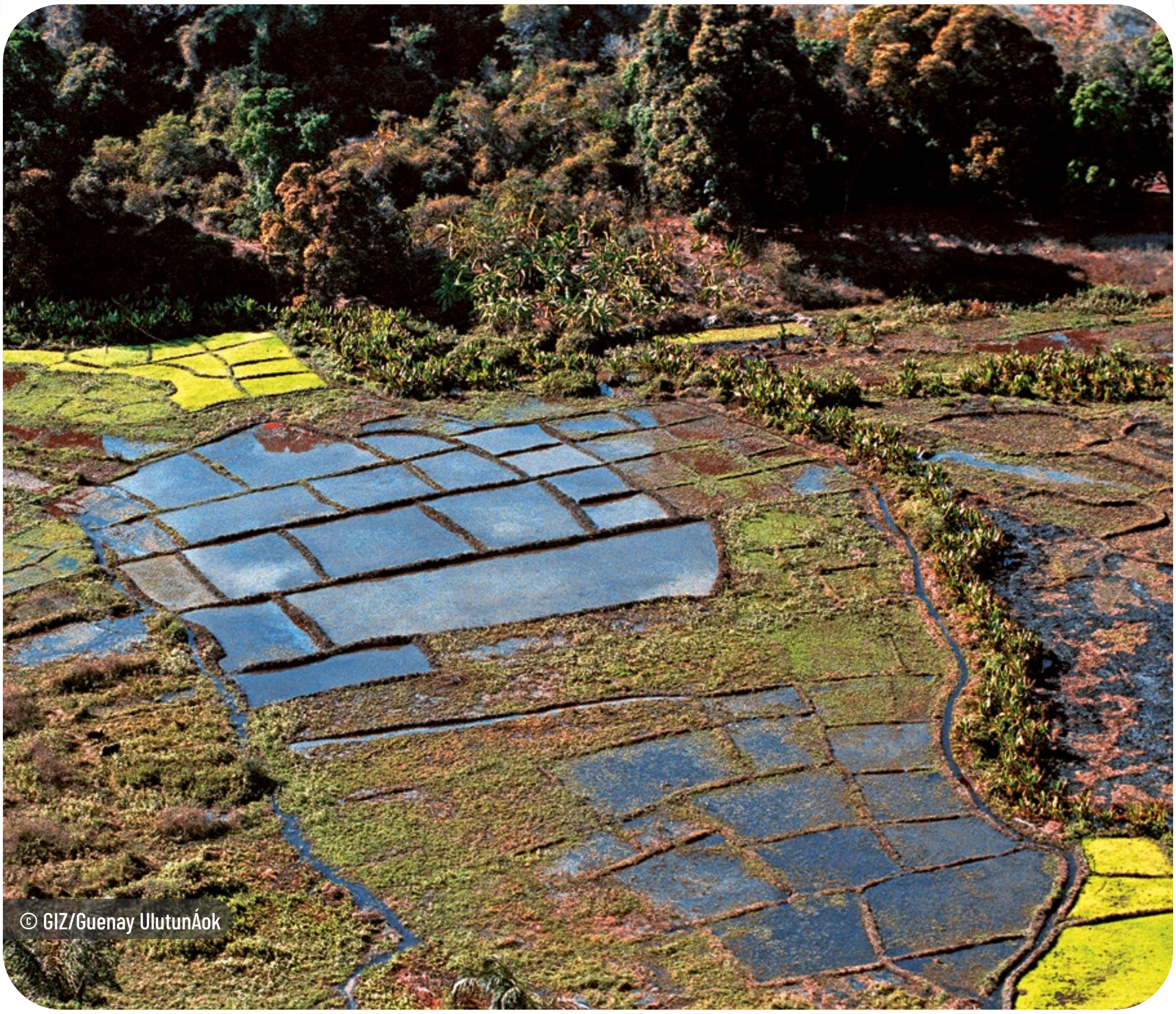
Parameter	N (%)	P (ppm)	K (% me)	SOC (%)	EA (cmol kg^{-1})	pH
Initial	0.21	15	0.78	2.26	0.4	4.51
Kitchen waste vermicompost	0.27	50	1.77	2.61	0.2	5.57
Market waste vermicompost	0.33	40	1.7	2.47	0.27	5.04
Tea waste vermicompost	0.27	50	1.94	2.61	0.23	5.28

Source: Created by the authors

Manure produced from the casts in vermicomposting. Job's farm in Marama South Location in Kakamega County.

Soil Fertility in Madagascar

Agriculture is fundamental to Madagascar's development, providing food security and livelihoods.It employs 70 per cent of the country's workforce and is the mainstay of the 64 per cent rural population.[55] A significant cause of land degradation and soil fertility decline in the country is slash-and-burn agriculture. It is a common traditional farming practice, locally known as *tavy*. Logging as well as the need for agricultural land are the main causes for extensive deforestation in the country.[55] Over time these practices have led to significant soil erosion and loss of soil organic matter. In pursuit for new agricultural lands, the vicious cycle is exacerbating land degradation and reducing agricultural productivity. Additionally, smallholder farmers have limited access to synthetic fertilisers, enhancing nutrient depletion without replenishing the nutrients mined. Addressing soil fertility decline and land degradation becomes imperative for the welfare of the country.


© GIZ/Guenay UlutunÁok

[55] Andrew Berley. "Madagascar: A Natural Solution to Soil Degradation and Slash-and-Burn Agriculture." (2019). https://www.worldfoodprize.org/documents/filelibrary/youth_programs/2019_gyi_papers/BerleyAndrew_EEFAB3F18A00F.pdf.

Crop residue management

Crop residue management refers to the practice of strategically handling and utilising the leftover plant material, such as stems, leaves and stalks, that remains on the farm after harvesting crops. This technology involves leaving them in place and incorporating them back into the soil or using the residues as forage for grazing livestock.

Crop residues help to improve soil health and fertility. Crop residues act as a natural mulch, covering the soil surface and helping to retain moisture, reduce erosion and suppress weed growth. As these residues decompose, they release organic matter and nutrients back into the soil, enriching its nutrient content and enhancing its structure. In the Madagascan highlands, retention of desmodium residue increased the total plant biomass, rice grain yields, soil nitrate content and total P uptake by rice.[56] Removal of these residues exposes the soil, enhancing moisture and nutrient losses by evaporation and volatilisation respectively, coupled with nutrient losses in the biomass. A study in the Malagasy Highlands recorded annual losses of 57 kg of N, 6 kg of P and 33 kg of K per hectare due to rice harvesting.[57] Such losses imply reduced crop productivity.

Lastly, crop residue retention potentially reduces the need for external fertilisers and herbicides. This reduces input costs for smallholder farmers and enhances environmental conservation.

More to know:

Learn more about ***crop residue management*** on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

Crop residues on a plot of land planted with maize and a local cowpea variety (Lojy zazamena). Andriambato, Antanambao Andranolava Commune.

[56] O Ratsiatosika et al. "Earthworm Functional Groups, Residue Quality and Management Impact on Upland Rice Growth and Yield: An Experimental Study in the Madagascar Highlands- Fdi:010087252- Horizon." (2019). https://www.documentation.ird.fr/hor/fdi:010087252.

[57] M. L. Fanjaniaina et al. "Biomass Harvesting Leads to Soil Acidification: A Study of Mixed Crop-Livestock Farming Systems in Madagascar" *Crop and Pasture Science* 72, no. 3 (March 24, 2021): 236–44. https://doi.org/10.1071/CP20499.

Soil Fertility in Benin

Agriculture has the dual role of economic and social development in Benin, accounting for about 32 per cent of the GDP and 70 per cent of the country's workforce.[58] Rural livelihoods are particularly dependent on natural resources with agriculture as the leading source. Moreover, a minority of urban households derive their income from agriculture. Despite its significance, food security remains a challenge in the country. With the rapid population growth of about three per cent and an urbanisation rate of 44 per cent,[59] addressing the challenge of soil fertility decline and general soil health deterioration is urgent. The increasing demand for land for agriculture as well as settling causes a strain on the resource, contributing to intensive agricultural use with intensive use of chemical fertilisers and pesticides. This is coupled with extensive erosion from deforestation. Consequently, these result in loss of fertile soil, reducing crop yields and diminishing the land's capacity to support agriculture in the long term. ProSoil supports smallholder, resource-poor farmers to adopt SLM practices to prevent further decline in soil productivity.

Harnessing velvet bean as a soil-enriching cover crop

ProSoil Benin promotes the cultivation of velvet bean (*Mucuna pruriens*) as a pure stand before cultivating other crops on the same land.

Mucuna in pure cultivation in Bantè. Bantè.

More to know:

Learn more about the the cultivation of ***velvet bean (Mucuna pruriens)*** on the WOCAT Global SLM Database!

Scan or click on the QR Code below:

Mucuna pruriens plays a vital role in soil management in agricultural systems. One of its key contributions lies in its ability to fix nitrogen from the atmosphere into the soil through a symbiotic relationship with nitrogen-fixing bacteria. This potentially increases soil fertility, reducing the need for synthetic fertilisers, which are costly for resource-poor farmers and leads to improved crop yields. ProSoil farmers have reported that maize yields on land previously cultivated with velvet bean range from 2.5 to 3 tonnes per hectare, compared to 1.5 tonnes per hectare on land without prior velvet bean cultivation. Similarly, a study in Southern Benin recorded increased N, SOM, SOC, P and grain yields of maize with the introduction of vervet bean (Table 7).[60] Improved crop yields are a boost on food availability and incomes of the farmers.

[58] Serge G. N. Ekpodessi and Hitoshi Nakamura. "Impact of Insecure Land Tenure on Sustainable Agricultural Development: A Case Study of Agricultural Lands in the Republic of Benin, West Africa." *Sustainability* 14, no. 21 (January 2022): 14041. https://doi.org/10.3390/su142114041.

[59] Kpade O. L. Hounkpatin et al. "Assessment of the Soil Fertility Status in Benin (West Africa) – Digital Soil Mapping Using Machine Learning." *Geoderma Regional* 28 (March 1, 2022): e00444. https://doi.org/10.1016/j.geodrs.2021.e00444.

Table 7: Effect of velvet bean on soil properties and maize grain yields in Benin[61]

Treatment	N (mg/kg)	SOM (mg/kg)	SOC (mg/kg)	P (mg/kg)	Maize grain yield t ha^{-1}
Initial	0.504	1.776	1.030	11.676	0.75±0,02
Maize only	0.476	1.957	1.135	14.325	0.75±0,02
Maize + fertiliser	0.686	2.194	1.272	16.179	2.78±0.04
Maize + mucuna	0.658	2.313	1.342	13.795	2.62±0,06
Maize + mucuna + fertiliser	0.518	2.265	1.314	20.153	2.08±0,08

Source: https://www.ajol.info/index.php/ijbcs/article/view/242219

Mucuna pruriens has a deep and extensive root system that helps to improve soil structure and prevent erosion. This is particularly important in areas where soil erosion is a significant threat to agricultural productivity and ecosystem health. Additionally, as a cover crop, it provides a natural mulch that helps to conserve soil moisture and suppress weed growth. Its foliage covers the soil reducing evaporation, thus helping to maintain soil moisture. Trials conducted on farmers' plots demonstrated an improvement in water infiltration rates ranging from 29 to 66 per cent in maize fields where velvet bean and pigeon pea (*Cajanus cajan*) were previously cultivated in Northern and Central Benin. Alongside improved soil pH, N and SOM, the soil conditions enhanced maize yields.[61] Mucuna pruriens is valuable in enhancing soil conservation and soil productivity.

[60] Ibouraïman Balogoun et al. "Agronomic Performance of Mucuna Pruriens on Maize Cultivation and Chemical Fertility of Ferralitic Soils in Southern Benin." CABI Databases, 2023. https://www.cabidigitallibrary.org/doi/full/10.5555/20230133421.

Key Challenges to Enhancing Adoption of SLM Practices for Improved Soil Fertility and Health

1. **Knowledge and awareness:** Many farmers and other relevant stakeholders may not be aware of the benefits of SLM practices or may have limited access to information about how to implement them effectively. This lack of knowledge can hinder the widespread adoption of SLM practices and prevent farmers from realising the potential benefits for their soil and crops.

   The efforts by GIZ through ProSoil involve capacity building and training of various stakeholders on SLM, enhancing knowledge and awareness. The WOCAT Global SLM Database strengthens this by providing a platform to enhance dissemination. Moreso, the standardised formats of documenting SLM practices in the database, including using widely accepted languages such as English and French, enhances global access.

2. **Infrastructure:** Infrastructure limitations, such as inadequate biochar kilns or city composting systems, can pose challenges to the adoption of SLM practices. Improving infrastructure in rural areas is crucial for supporting the adoption of SLM practices and enhancing soil fertility and health.

   ProSoil farmers utilise locally or easily available resources for making some of the SLM infrastructure like shades for vermicomposting. ProSoil provides biochar kilns and collaborates with municipalities in the provision of community infrastructure such as city composting units.

3. **Availability of inputs:** The availability of inputs, such as seeds and seedlings for cover crops or nitrogen-fixing plants like Mucuna pruriens, can be a barrier to the adoption of SLM practices. In some cases, farmers may have limited access to quality seeds or may face challenges in obtaining the specific inputs needed for implementing SLM practices. This lack of availability can hinder farmers' ability to adopt these practices and can limit their effectiveness in improving soil fertility and health.

   ProSoil provides seeds or seedlings for the first seasons. Moreover, the programme uses a farmer-led model, where selected farmers are equipped with skills and knowledge for multiplication, enhancing the cultivation of these soil-enriching crops.

4. **Policy:** Policy frameworks and regulations can significantly influence the adoption of SLM practices. However, inconsistent or inadequate policies related to land use, agriculture and environmental conservation can create barriers to the adoption of SLM practices. Lack of supportive policies or unclear regulations may discourage farmers from investing in SLM practices or may hinder efforts to scale up adoption at the national or regional level. Addressing policy challenges and creating enabling policy environments are essential for promoting the adoption of SLM practices and improving soil fertility and health.

[61] JAD Dossou et al. "Agronomic Evaluation of the Effects of Two Green Manure Cover Crops on Maize (Zea Mays) Cultivation in Four-Agroecological Zones of Benin." (2022).

Recommendations and Conclusion

SLM practices, including application of lime, livestock urine, biochar, bioslurry, compost and vermicompost, crop residue management, ISFM practices and FREGs as well as the cultivation of Mucuna pruriens, have proved to be effective in soil conservation and improvement of soil health (Appendix 1). The practices are low cost, offering cost effective solutions for smallholder farmers. Additionally, some are complementary and their integration will only boost soil productivity. The application of these practices optimises soil health while minimising environmental impacts. Given the current global challenges of land degradation and food insecurity, these practices offer solutions even amidst the changing climate. In essence, they enhance the sequestration of SOC, thus building resilience in food and agricultural systems in the long-term and mitigating the impacts of climate change. SLM practices improve soil fertility and health for sustainable food and agricultural systems.

SLM practice	N	P	K	Ca	Erosion control	Water retention	Pest control
Livestock urine collection and use (T)	■	■	■	■			■
Bioslurry (T)	■			■	■	■	■
Treating acid soils with lime (T)	■	■	■				
Integrated soil fertility management (ISFM) (A)	■	■	■	■	■	■	
Farmers research and extension group (FREG) (A)	■	■	■	■	■	■	■
Biochar application on homestead land (T)	■	■	■	■		■	
City compost: a solution for waste management and soil health improvement (T)	■	■	■	■		■	
Vermicomposting: an effective liquid fertiliser and biopesticide (T)	■	■	■	■		■	■
Crop residue management (T)	■				■	■	
Harnessing mucuna as a soil-enriching cover crop (T)	■	■		■	■	■	

■ = Improved through practice

The successful adoption of these SLM practices necessitates strengthened partnerships and collaborations with a range of stakeholders. Partnerships with non-governmental organisations (NGOs) can provide valuable expertise and resources for implementing capacity-building and training programmes to enhance knowledge and awareness of SLM practices. Collaborations with private companies can facilitate infrastructure development by leveraging their resources and expertise in technology and innovation. Engaging with local governments is crucial for securing support and funding for SLM infrastructure, projects and policy development. Importantly, partnerships with the general public, especially farmers, are essential for the successful adoption of SLM practices. Farmers play a key role in implementing these practices on the ground, and their involvement is crucial for the long-term success of SLM initiatives. Farmers should be given the necessary support and resources to integrate SLM into agricultural systems. Strengthening these partnerships is essential for scaling up SLM and ensuring its sustainability.

References

Abebe, Tilahun Gisila, Mohan Rao Tamtam, Amare Ayalew Abebe, Kitaw Abraham Abtemariam, Tewodros Geremew Shigut, Yared Abate Dejen, and Endayehu Gebeyhu Haile. "Growing Use and Impacts of Chemical Fertilizers and Assessing Alternative Organic Fertilizer Sources in Ethiopia." Applied and Environmental Soil Science 2022 (March 20, 2022): e4738416. https://doi.org/10.1155/2022/4738416.

Abi, Meskerem, Aad Kessler, Peter Osterveer, and Degefa Tolossa. "Enabling Policy and Institutional Environment for Scaling-Up Sustainable Land Management in Central Highlands of Ethiopia." Ethiopian Journal of Development Research 43, no. 1 (2021): 21–50. https://www.ajol.info/index.php/ejdr/article/view/238258.

Adolwa, Ivan Solomon, Stefan Schwarze, and Andreas Buerkert. "Impacts of Integrated Soil Fertility Management on Yield and Household Income: The Case of Tamale (Ghana) and Kakamega (Kenya)." Ecological Economics 161 (July 1, 2019): 186–92. https://doi.org/10.1016/j.ecolecon.2019.03.023.

Alemu, Erkihun, Yihenew G. Selassie, and Birru Yitaferu. "Effect of Lime on Selected Soil Chemical Properties, Maize (Zea Mays L.) Yield and Determination of Rate and Method of Its Application in Northwestern Ethiopia." Heliyon 8, no. 1 (January 2022): e08657. https://doi.org/10.1016/j.heliyon.2021.e08657.

Amede, Tilahun, S Schulz, J Warner, and Solomon Tefera. "Managing Acid Soils for Reclaiming Livelihoods in Ethiopia." (2019). ICRISAT-GIZ, Addis Ababa. https://hdl.handle.net/10568/101619.

Amoussouga Gero, Abraham, and Aklesso Y. G. Egbendewe. "Macroeconomic Effects of Semi-Subsistence Agricultural Productivity Growth: Evidence from Benin and Extension to the WAEMU Countries." Scientific African 7 (March 1, 2020): e00222. https://doi.org/10.1016/j.sciaf.2019.e00222.

Balogoun, Ibouraïman, Sylvain Ogoudjobi, Ezéchiel Bero, Bienvenu Dahodo, Robert Vidinhouede, and Pascal Houngnandan. "Agronomic Performance of Mucuna Pruriens on Maize Cultivation and Chemical Fertility of Ferralitic Soils in Southern Benin." CABI Databases, (2023). https://www.cabidigitallibrary.org/doi/full/10.5555/20230133421.

Basak, Nirmalendu, Biswapati Mandal, Arvind Kumar Rai, and Piu Basak. "Soil Quality and Productivity Improvement: Indian Story." Proceedings of the Indian National Science Academy 87, no. 1 (March 1, 2021): 2–10. https://doi.org/10.1007/s43538-021-00007-8.

Berley, Andrew. "Madagascar: A Natural Solution to Soil Degradation and Slash-and-Burn Agriculture." (2019). https://www.worldfoodprize.org/documents/filelibrary/youth_programs/2019_gyi_papers/BerleyAndrew_EEFAB3F18A00F.pdf.

Blanco, Humberto, and Rattan Lal. "Soil Fertility Management." In Soil Conservation and Management, edited by Humberto Blanco and Rattan Lal, 363–90. Cham: Springer Nature Switzerland, (2023). https://doi.org/10.1007/978-3-031-30341-8_15.

Chaka, Bakari, Osano A, Githua D, Osano A, Githua D, and Osigo M. "Optimization of Anti-Microbial and Pesticidal Efficacies of Bio-Slurry Using Terminalia b. and Acanthaceae Spp. Extracts." International Journal of Research and Innovation in Applied Science 4, no. 12 (2019). https://www.rsisinternational.org/journals/ijrias/DigitalLibrary/Vol.4&Issue12/31-41.pdf.

Chand, Ramesh, Pramod Joshi, and Shyam Khadka, eds. "Indian Agriculture Towards 2030: Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems." Singapore: Springer Nature Singapore, (2022). https://doi.org/10.1007/978-981-19-0763-0.

Chirwa, Paxie W., Colin R. Black, Chin K. Ong, and Jumanne Maghembe. "Nitrogen Dynamics in Cropping Systems in Southern Malawi Containing Gliricidia Sepium, Pigeonpea and Maize." Agroforestry Systems 67, no. 1 (April 2006): 93–106. https://doi.org/10.1007/s10457-005-0949-z.

Devasena, M., and V. Sangeetha. "Cow Urine: Potential Resource for Sustainable Agriculture." In Emerging Issues in Climate Smart Livestock Production, 247–62. Elsevier, (2022). https://doi.org/10.1016/B978-0-12-822265-2.00007-7.

Dossou, JAD, RVC Diogo, MG Gbedjisokpa, AB Seidou, GA Awéha, and BK Paul. "Agronomic Evaluation of the Effects of Two Green Manure Cover Crops on Maize (Zea Mays) Cultivation in Four-Agroecological Zones of Benin." Proceedings of the 20th Agronomy Australia Conference, 2022 Toowoomba Qld. https://www.agronomyaustraliaproceedings.org/images/sampledata/2022/DiversifyingCroppingSystems/ASAdiogo_r_600s.pdf.

Ekpodessi, Serge G. N., and Hitoshi Nakamura. "Impact of Insecure Land Tenure on Sustainable Agricultural Development: A Case Study of Agricultural Lands in the Republic of Benin, West Africa." Sustainability 14, no. 21 (January 2022): 14041. https://doi.org/10.3390/su142114041.

Fanjaniaina, M. L., J. Larvy Delarivière, P. Salgado, E. Tillard, L. Rabeharisoa, and T. Becquer. "Biomass Harvesting Leads to Soil Acidification: A Study of Mixed Crop-Livestock Farming Systems in Madagascar." Crop and Pasture Science 72, no. 3 (March 24, 2021): 236–44. https://doi.org/10.1071/CP20499.

FAO. "Kenya at a Glance | FAO in Kenya | Food and Agriculture Organization of the United Nations." (Accessed March 10, 2024). https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/.

FAO. "World Soil Day 2022: FAO Publishes First Global Report on Black Soils." Newsroom, (2022). https://www.fao.org/newsroom/detail/world-soil-day-2022-fao-global-report-black-soils/en.

Geremew, Biramo, Girma Jibat, and Birhanu Biazin. "Effects of Dry Bioslurry and Chemical Fertilizers on Tomato Growth Performance, Fruit Yield and Soil Properties under Irrigated Condition in Southern Ethiopian." African Journal of Agricultural Research 14 (October 31, 2019): 1685–92. https://doi.org/10.5897/AJAR2019.14372.

Getachew, Agegnehu, Yirga Chilot, and James Warner. "Soil Acidity in Ethiopia, Cause, Effects, Management and Policy Consideration." IFPRI, EIAR, (2018).

Gulati, Ashok, and Ritika Juneja. "Transforming Indian Agriculture." In Indian Agriculture Towards 2030: Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems, edited by Ramesh Chand, Pramod Joshi, and Shyam Khadka, 9–37. Singapore: Springer Nature, (2022). https://doi.org/10.1007/978-981-19-0763-0_2.

Gupta, Gauri Shankar. "Land Degradation and Challenges of Food Security." Review of European Studies 11, no. 1 (2019). https://doi.org/10.5539/res.v11n1p63.

Haile, Getahun, Habtamu Berihun, Helina Abera, Getachew Agegnehu, and Mulugeta Lemenih. "Soil Properties, Crop Yield, and Economic Return in Response to Lime Application on Acidic Nitisols of Southern Highlands of Ethiopia." International Journal of Agronomy 2023 (December 29, 2023): e6105725. https://doi.org/10.1155/2023/6105725.

Hailemichael, Selam, and Ruth Haug. "The Use and Abuse of the 'Model Farmer' Approach in Agricultural Extension in Ethiopia." The Journal of Agricultural Education and Extension 26, no. 5 (October 19, 2020): 465–84. https://doi.org/10.1080/1389224X.2020.1757475.

Hailu, Mekonnen, Degefa Tolosa, Belay Kassa, and Anteneh Girma. "Understanding Factors Affecting the Performance of Agricultural Extension System in Ethiopia." Ethiopian Journal of Agricultural Sciences 30, no. 4 (October 31, 2020): 237–63. https://www.ajol.info/index.php/ejas/article/view/201145.

Hörner, Denise, and Meike Wollni. "Does Integrated Soil Fertility Management Increase Returns to Land and Labor?" Agricultural Economics 53, no. 3 (2022): 337–55. https://doi.org/10.1111/agec.12699.

———. "Integrated Soil Fertility Management and Household Welfare in Ethiopia." Food Policy 100 (April 1, 2021): 102022. https://doi.org/10.1016/j.foodpol.2020.102022.

Hossain, Akbar, Timothy J. Krupnik, Jagadish Timsina, M. Golam Mahboob, Apurbo Kumar Chaki, Muhammad Farooq, Rajan Bhatt, Shah Fahad, and Mirza Hasanuzzaman. "Agricultural Land Degradation: Processes and Problems Undermining Future Food Security." In Fahad, S., et al. Environment, Climate, Plant and Vegetation Growth. Springer, Cham. (2020). https://doi.org/10.1007/978-3-030-49732-3_2.

Hounkpatin, Kpade O. L., Aymar Y. Bossa, Yacouba Yira, Mouïnou A. Igue, and Brice A. Sinsin. "Assessment of the Soil Fertility Status in Benin (West Africa) – Digital Soil Mapping Using Machine Learning." Geoderma Regional 28 (March 1, 2022): e00444. https://doi.org/10.1016/j.geodrs.2021.e00444.

IASET. "The Impact of Secondary Macro Nutrients on Crop Production." SSRN Scholarly Paper. Rochester, NY, (June 1, 2021). https://doi.org/10.2139/ssrn.3962862.

Jain, Mayur Shirish, and Ajay S. Kalamdhad. "Soil Revitalization via Waste Utilization: Compost Effects on Soil Organic Properties, Nutritional, Sorption and Physical Properties." Environmental Technology & Innovation 18 (May 1, 2020): 100668. https://doi.org/10.1016/j.eti.2020.100668.

Javed, Ansa, Eeman Ali, Khansaa Binte Afzal, Asma Osman, and Dr Samreen Riaz. "Soil Fertility: Factors Affecting Soil Fertility, and Biodiversity Responsible for Soil Fertility." International Journal of Plant, Animal and Environmental Sciences 12, no. 1 (March 31, 2022): 21–33. https://www.fortunejournals.com/articles/soil-fertility-factors-affecting-soil-fertility-and-biodiversity-responsible-for-soil-fertility.html.

Kebede, Tsehay, Yadessa Gonfa Keneni, Abate Feyissa Senbeta, and Getachew Sime. "Effect of Bioslurry and Chemical Fertilizer on the Agronomic Performances of Maize." Heliyon 9, no. 1 (January 2023): e13000. https://doi.org/10.1016/j.heliyon.2023.e13000.

Laekemariam, Fanuel, and Kibebew Kibret. "Extent, Distribution, and Causes of Soil Acidity under Subsistence Farming System and Lime Recommendation: The Case in Wolaita, Southern Ethiopia." Applied and Environmental Soil Science 2021 (September 26, 2021): e5556563. https://doi.org/10.1155/2021/5556563.

Lekamoi, Upendo. "Effects of Tephrosia Vogelii Formulation with Rabbit Urine on Insect Pests and Pollinators of Sesame in Singida, Tanzania." Thesis, NM-AIST, (2022). https://doi.org/10.58694/20.500.12479/1496.

Lolamo, Tseganesh, Abate Feyissa Senbeta, Yadessa Gonfa Keneni, and Getachew Sime. "Effects of Bio-Slurry and Chemical Fertilizer Application on Soil Properties and Food Safety of Tomato (Solanum Lycopersicum Mill.)." Applied and Environmental Soil Science 2023 (March 20, 2023): e6694536. https://doi.org/10.1155/2023/6694536.

Majer, Stefan, Katja Oehmichen, Josephin Helka, Christoph Siol, and Uta Schmieder. "Greenhouse Gas Emissions from Terra Preta Substrates in India." GIZ, (2023). https://www.giz.de/en/downloads/giz2023-en-greenhouse-gas-emissions-from-terra-preta-substrates-in-india.pdf.

Mathenge, Catherine, Moses Thuita, Cargele Masso, Joseph Gweyi-Onyango, and Bernard Vanlauwe. "Variability of Soybean Response to Rhizobia Inoculant, Vermicompost, and a Legume-Specific Fertilizer Blend in Siaya County of Kenya." Soil and Tillage Research 194 (November 1, 2019): 104290. https://doi.org/10.1016/j.still.2019.06.007.

Meena, Hari Mohan, and H. C. Prakasha. "Effect of Biochar, Lime and Soil Test Value Based Fertilizer Application on Soil Fertility, Nutrient Uptake and Yield of Rice-Cowpea Cropping System in an Acid Soil of Karnataka." Journal of Plant Nutrition 43, no. 17 (July 14, 2020): 2664–79. https://doi.org/10.1080/01904167.2020.1793188.

Melash, Anteneh Agezew, Amare Assefa Bogale, Abeje Tafere Migbaru, Gashaw Gismu Chakilu, Attila Percze, Éva Babett Ábrahám, and Dejene K. Mengistu. "Indigenous Agricultural Knowledge: A Neglected Human Based Resource for Sustainable Crop Protection and Production." Heliyon 9, no. 1 (January 2023): e12978. https://doi.org/10.1016/j.heliyon.2023.e12978.

Mochache, Miriam Ogake, Rebecca Yegon, and Onesmus Ngetich. "Performance of Vermicomposted Wastes for Tomato (Lycopersicon Esculentum Mill.), Production: A Case Study of Embu, Kenya." IJROWA 10, no. 4 (December 2021). https://doi.org/10.30486/IJROWA.2021.1904563.1103.

Mulema, Annet A., Wellington Jogo, Elias Damtew, Kindu Mekonnen, and Peter Thorne. "Women Farmers' Participation in the Agricultural Research Process: Implications for Agricultural Sustainability in Ethiopia." International Journal of Agricultural Sustainability 17, no. 2 (March 4, 2019): 127–45. https://doi.org/10.1080/14735903.2019.1569578.

Negese, Wegene. "Review on the Extent of Acid Soil in Ethiopia, Its Impact and Management Methods." Journal of Biology, Agriculture and Healthcare 9, no. 15 (May 19, 2021): 24–36. https://www.iiste.org/Journals/index.php/JBAH/article/view/49143/50773.

Neglo, Komikouma Apelike Wobuibe, Tnsue Gebrekidan, and Kaiyu Lyu. "The Role of Agriculture and Non-Farm Economy in Addressing Food Insecurity in Ethiopia: A Review." Sustainability 13, no. 7 (January 2021): 3874. https://doi.org/10.3390/su13073874.

Nyamangara, Justice, Jefline Kodzwa, Esther Nyaradzo Masvaya, and Gabriel Soropa. "Chapter 5 - The Role of Synthetic Fertilizers in Enhancing Ecosystem Services in Crop Production Systems in Developing Countries." In The Role of Ecosystem Services in Sustainable Food Systems, edited by Leonard Rusinamhodzi, 95-117. Academic Press, (2020). https://doi.org/10.1016/B978-0-12-816436-5.00005-6.

Patel, CC, Digvijay Singh, V Sridhar, Alka Choudhary, Ashish Dindod, and SR Padaliya. "Bioefficacy of Cow Urine and Different Types of Bio-Pesticide against Sucking Insect Pests of Cowpea." International Journal of Chemical Studies 7, no. 3 (2019): 4664-4667.

Pradhan, Swati, Sudhanshu Verma, Dr Kumari, and Yashwant Singh. "Bio-Efficacy of Cow Urine on Crop Production: A Review." International Journal of Chemical Studies 6, no. 3 (January 1, 2018) 298-301. https://www.chemijournal.com/archives/?year=2018&vol=6&issue=3&ArticleId=2466&si=false.

Rajput, Richa, Priya Pokhriya, Pooja Panwar, A. Arunachalam, and Kusum Arunachalam. "Soil Nutrients, Microbial Biomass, and Crop Response to Organic Amendments in Rice Cropping System in the Shiwaliks of Indian Himalayas." International Journal of Recycling of Organic Waste in Agriculture 8, no. 1 (March 1, 2019): 73–85. https://doi.org/10.1007/s40093-018-0230-x.

Ratsiatosika, O, L Benard, B Rabary, I Rainihanjarimanana, R Randriamanantsoa, T Razafimbelo, M Razafindrakoto, J Trap, and E Blanchart. "Earthworm Functional Groups, Residue Quality and Management Impact on Upland Rice Growth and Yield : An Experimental Study in the Madagascar Highlands." Journal of Experimental Agriculture International 30, no. 5 (2019). https://www.documentation.ird.fr/hor/fdi:010087252.

Reich, H. Eswaran, R. Lal, P. F. "Land Degradation: An Overview." In Response to Land Degradation. CRC Press, (2001).

Singh, Anil, Ashutosh Upadhyaya, Sonia Kumari, Prem Sundaram, and Pawan Jeet. "Role of Agriculture in Making India $5 Trillion Economy under Corona Pandemic Circumstance." Journal of AgriSearch 6 (June 8, 2020). https://doi.org/10.21921/jas.v6i02.18097.

Singh, Gurpreet, Manpreet Singh Mavi, Om Parkash Choudhary, Naveen Gupta, and Yadvinder Singh. "Rice Straw Biochar Application to Soil Irrigated with Saline Water in a Cotton-Wheat System Improves Crop Performance and Soil Functionality in North-West India." Journal of Environmental Management 295 (October 1, 2021): 113277. https://doi.org/10.1016/j.jenvman.2021.113277.

Snapp, Sieglinde, Tek Bahadur Sapkota, Jordan Chamberlin, Cindy Marie Cox, Samuel Gameda, Mangi Lal Jat, Paswel Marenya, et al. "Spatially Differentiated Nitrogen Supply Is Key in a Global Food–Fertilizer Price Crisis." Nature Sustainability 6, no. 10 (October 2023): 1268–78. https://doi.org/10.1038/s41893-023-01166-w.

Sridhar, Adithya, Akash Balakrishnan, Meenu Mariam Jacob, Mika Sillanpää, and Nanditha Dayanandan. "Global Impact of COVID-19 on Agriculture: Role of Sustainable Agriculture and Digital Farming." Environmental Science and Pollution Research 30, no. 15 (March 1, 2023): 42509–25. https://doi.org/10.1007/s11356-022-19358-w.

Srivastava, Priyanka, Manju Balhara, and Bhoopander Giri. "Soil Health in India: Past History and Future Perspective." In Soil Health, edited by Bhoopander Giri and Ajit Varma, 1–19. Soil Biology. Cham: Springer International Publishing, (2020). https://doi.org/10.1007/978-3-030-44364-1_1.

Statista. "Global Fertilizer Consumption by Nutrient 1965-2021." Statista, (2023). https://www.statista.com/statistics/438967/fertilizer-consumption-globally-by-nutrient/.

Stellmacher, Till, and Girma Kelboro. "Family Farms, Agricultural Productivity, and the Terrain of Food (In)Security in Ethiopia." Sustainability 11, no. 18 (January 2019): 4981. https://doi.org/10.3390/su11184981.

Stewart, Zachary, Gary Pierzynski, B Jan Middendorf, and P V Vara Prasad. "Approaches to Improve Soil Fertility in Sub-Saharan Africa." Journal of Experimental Botany71, no. 2 (January 7, 2019): 632–641. https://doi.org/10.1093/jxb/erz446.

Takala, Bikila. "Soil Acidity and Its Management Options in Western Ethiopia: Review." Environmental Earth Sciences 9, no. 10 (October 31, 2019): 27–35. https://doi.org/10.7176/JEES/9-10-04.

Temesgen, J., and M. Ahmed, eds. "Water and Cow Urine Quenched Biochar Rate Effect on Yield and Yield Parameters of Wheat." International Journal of Agricultural Research, Innovation and Technology (IJARIT) 10, no.1 (2020): 35–39. https://doi.org/10.22004/ag.econ.304060.

UNCCD. "Chronic Land Degradation: UN Offers Stark Warnings and Practical Remedies in Global Land Outlook 2." UNCCD, (2022). https://www.unccd.int/news-stories/press-releases/chronic-land-degradation-un-offers-stark-warnings-and-practical.

USAID. "Agriculture and Food Security | Ethiopia." U.S. Agency for International Development, (April 27, 2023). https://www.usaid.gov/ethiopia/agriculture-and-food-security.

Wiesmeier, Martin, Livia Urbanski, Eleanor Hobley, Birgit Lang, Margit von Lützow, Erika Marin-Spiotta, Bas van Wesemael, et al. "Soil Organic Carbon Storage as a Key Function of Soils – A Review of Drivers and Indicators at Various Scales." Geoderma 333 (January 1, 2019): 149–62. https://doi.org/10.1016/j.geoderma.2018.07.026.

Willy, Daniel Kyalo, Milu Muyanga, Joseph Mbuvi, and Thomas Jayne. "The Effect of Land Use Change on Soil Fertility Parameters in Densely Populated Areas of Kenya." Geoderma 343 (June 1, 2019): 254–62. https://doi.org/10.1016/j.geoderma.2019.02.033.

Wocat. "SLM." Wocat. (Accessed February 22, 2024). https://www.wocat.net/en/slm/.

World Bank. "Ethiopia: Overview." World Bank. (Accessed February 22, 2024). https://www.worldbank.org/en/country/ethiopia/overview.

Zerssa, Gebeyanesh, Debela Feyssa, Dong-Gill Kim, and Bettina Eichler-Löbermann. "Challenges of Smallholder Farming in Ethiopia and Opportunities by Adopting Climate-Smart Agriculture." Agriculture 11, no. 3 (March 2021): 192. https://doi.org/10.3390/agriculture11030192.

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