Optimising Soil Health in Africa

- A holistic approach to fertilizer management using in situ and ex situ resources -

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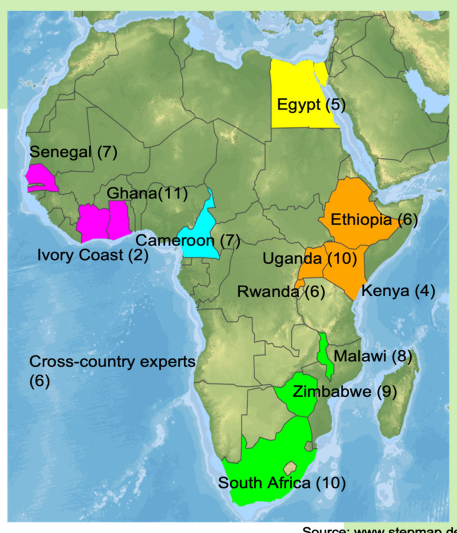
Background

- **Addressing soil health is a key means** to increase crop productivity, support yield stability and agronomic fertilizer efficiency (Vanlauwe et al., 2023).
- A **holistic approach** is central to reducing **soil degradation** (e.g., erosion, nutrient loss), optimising fertiliser and soil organic carbon management.
- In Africa, both ex situ **mineral and organic fertilizers** are currently **scarce** and **expensive resources** (Freyer et al., 2024).
- Many well-known **on-farm practices** (in situ) for increasing soil productivity are not being applied, and the potential for **ex situ organic resources** through the recycling of organic wastes is not widely being realized (Freyer et al., 2024).

Methods

1. Data

- **Literature review:** Scientific publications; reports; databases (e.g., FAOSTAT)
- **Empirical data / Semi-quantitative interviews:**
  5 African sub-regions with 12 countries
  83 expert interviews and 6 cross-country experts



Source: www.stepmap.de

2. Analysis and results

- **Biomass and nutrient quantities (literature; own calculations):** country specific, farm specific
- **Development of an integrated fertilizer management strategy** (semi-quantitative)

Fertilizer strategy embedded in an overall sustainable farming system approach				
Land use systems	Arable land	Permanent grassland	Agroforestry	Woodlots
	Crop rotation	Site specific use types	Trees, alley crops, hedges	Trees
	Forage legumes > 10% Diverse cereals, grain legumes and root crops Undersowing / relay cropping / intercropping Push-pull system	Grasses, herbs and legumes adapted to the site-specific conditions Management, e.g., animal dung distribution Fencing	Species combination of mainly leguminous shrubs and trees	Diverse leguminous species
pH-regulation	Continuous liming			
Water management	Adapted tillage, mulching, wind breaks, high organic matter application, water saving and collection techniques			
On-farm organic fertilizers	Comprehensive collection and storage of solid / liquid manure or vermicompost; technology for processing and application; Soil amendments (biochar)			
On-farm biofertilizers	Plant teas - own production; MO's adapted to and multiplicated at the farm; precise application techniques			
Off-farm organic fertilizers	Compost, frass fertilizer, and bio-slurry according to nutrient (inclusive N-fixation) and carbon balance			
Off-farm biofertilizers	Rhizobia for all legumes; Certified biofertilizers (incl. plant teas)			
Inorganic fertilizers	N - 50 kg/ha^{-1}, e.g., for maize and wheat / P – 10 kg/ha^{-1}, e.g., for legumes / K – 20 kg/ha^{-1}, e.g., for root crops according to nutrient balance			
Tillage systems	Orientation: Shallow loosening and mixing; deep loosening			

Figure 1. Fertilizer strategy embedded in an overall sustainable farming system approach (Source: own)

Optimising Soil Health

Toolbox of agronomic practices & fertilizers

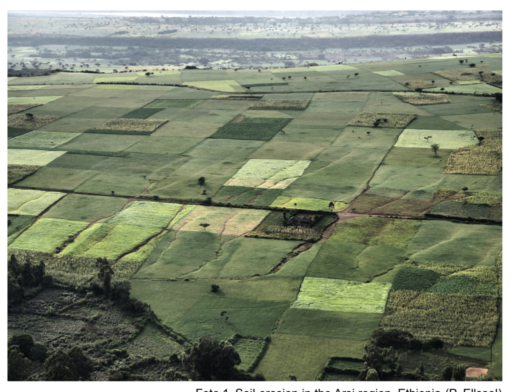


Foto 1. Soil erosion in the Arsi region, Ethiopia (P. Ellssel)

Fertilisers managed according to 4R (APNI, 2022):

- **Right Source**: The selection of fertilizers should consider both short- and long-term nutrient and carbon strategies, as well as additional practices (refer to Table 1 + 2).
- **Right Rate**: Determining the appropriate rate involves assessing:
  --> Overall soil nutrient content
  --> Erosion activity over the past decade
  --> Potential nutrient residues from previous crops
  --> Intended crop yield
  --> Nutrient balance
- **Right Place**: Placement should consider:
  --> The crop's rooting system
  --> Plant density
  --> Soil conditions
  --> Tillage system
- **Right Time**: Timing should take into account:
  --> Crop growth stages
  --> Nutrient availability of different minerals
  --> Soil and weather conditions
  --> The need to incorporate organic fertilizers into the soil


Foto 2. Soil health workshop Uganda (B. Freyer)

Table 2: Impact of cropping system, soil tillage and fertilizer inputs on soil and crop characteristics (Source: own / diverse literature)

Toolbox of input factors		Soil biology	Soil C stock[1]	Soil physics[2]	Soil pH	Soil nutrient stock	Nutrient availability N	Nutrient availability P	Nutrient availability K	Crop yield (Short-term)	Soil and crop health	Weed re-gulation
Crops	Forage legumes (two to three seasons)	(+++)	(+++)	(+++)	(+)	N: (++)	(+++)	(+)	(+)	(++/+++)	(+++)	(+++)
Crops	Multipurpose legumes (MPL) (one season)	(++)	(++)	(++)	(+)	(++)	(++)	(+)	(+)	(++)	(++)	(++)
Crops	High crop diversity (crop rotation > 5 crops)	(++)	(+/++)	(++)	(0/+)	(+)	(++)	(++)	(++)	(++/+++)	(+++)	(++)
Crops	Intercropping / Mixed legumes / Relay cropping	(+)	(+)	(+)	(0/+)	(+)	(++)	(+)	(+)	(++)	(++)	(+)
Crops	Cover crops	(+/++)	(+/++)	(++)	(0/+)	N: (0/++)	(0/++)	(+)	(+)	(++)	(++)	(+/++)
Crops	Leguminous shrubs / alley crops	(++)	(+++)	(+++)	(0/+)	N: (+/++)	(++)	(+)	(+)	(++)	(+++)	(+)
Crops	Agroforestry	(++)	(+++)	(+++)	(+)	N: (0/++)	(++)	(+)	(+)	(++)	(+++)	(+)
Various organic biomass (in situ)	Fresh green manure mulch (also cut and carry)	(++)	(+/++)	(+/++)	(+)	(+/++)	(++)	(+)	(+)	(+/++)	(++)	(+/++)
Various organic biomass (in situ)	Plant-based compost	(+++)	(+++)	(+++)	(+)	(+/++)	(+/++)	(+/++)	(+/++)	(+/++)	(+++)	0
Various organic biomass (in situ)	Fresh animal manure	(++)	(++)	(++)	0	(++)	(++)	(+)	(++)	(+/++)	(++)	0
Various organic biomass (in situ)	Animal manure compost	(+++)	(+++)	(+++)	(+)	(+/++)	(++)	(++)	(++)	(+/++)	(+++)	0
Various organic biomass (in situ)	Animal bioslurry	(+)	(+)	(+)	(+/++)	(++)	(+++)	(+++)	(+++)	(+++)	(+)	0
Various organic biomass (in situ)	Plant-based bioslurry	(+)	(+)	(+)	(+/++)	(++)	(+++)	(+++)	(+++)	(+++)	(+)	0
Various organic biomass (in situ)	Bioslurry compost	(++)	(++/+++)	(++)	(+)	(++)	(++)	(++)	(++)	(++/+++)	(+)	0
Various organic biomass (in situ)	Vermicompost	(+++)	(+++)	(+++)	(+)	(++)	(++)	(++)	(++)	(++)	(+++)	0
Mineral fertilizers	Urea	(++)	(+)	(+)	(–)	(++)	(+++)	0	0	(+++)	(++)	0
Mineral fertilizers	Ammonium Nitrate	(++)	(+)	(+)	(–)	(++)	(+++)	0	0	(+++)	(++)	0
Mineral fertilizers	Urea-Ammonium Nitrate (UAN)	(--)	(--)	0	(---)	(++)	(+++)	0	0	(+++)	(–)	0
Mineral fertilizers	Calcium Ammonium Nitrate (CAN)	0	0	0	0	(++)	(+++)	0	0	(+++)	0	0
Mineral fertilizers	Triple Superphosphate (TSP)	(--)	0	0	0	(+++)	0	(+++)	0	(++)	0	0
Mineral fertilizers	Diammonium Phosphate (DAP)	(--)	0	0	(--)	(+++)	(++)	(+++)	0	(+++)	0	0
Mineral fertilizers	Muriate of Potash (MOP)	(-)	0	0	(---)	(+++)	0	0	(+++)	(++)	0	0
Mineral fertilizers	Sulphate of Potash (SOP)	(-)	0	0	0	(+++)	0	0	(+++)	(++)	0	0
Mineral fertilizers	NPK Blends	(--)	(--)	0	(--)	(+++)	(+++)	(+++)	(+++)	(+++)	0	0
Ex situ organic biomass	Household waste compost	(+++)	(+++)	(+++)	(+)	(+/++)	(+/++)	(+/++)	(+/++)	(+/++)	(++)	0
Ex situ organic biomass	Market waste compost	(+++)	(+++)	(+++)	(+)	(+/++)	(+/++)	(+/++)	(+/++)	(+/++)	(++)	0
Ex situ organic biomass	Agroprocessing residue compost	(+++)	(+++)	(+++)	(+)	(+/++)	(+/++)	(+/++)	(+/++)	(+/++)	(++)	0
Ex situ organic biomass	Slaugtherhouse residue compost	(+++)	(+++)	(+++)	(+)	(++)	(++)	(++)	(++)	(++)	(++)	0
Ex situ organic biomass	Black soldier fly compost	(+++)	(+++)	(+++)	(+)	(++)	(++)	(++)	(++)	(++)	(+++)	0
Ex situ organic biomass	Human faeces co-compost	(+++)	(+++)	(+++)	(+)	(++)	(++)	(++)	(++)	(++)	(++)	0
Soil amendments	Biochar	(++/+++)	(+++)	(+++)	(0/+)	(+/+++)	(+/+++)	(+/+++)	(+/+++)	(++)	(+++)	0
Soil amendments	Lime	(++)	0	(+++)	(+++)	(+/++)	(+++)	(+++)	(+++)[5]	(++/+++)	(++)	0
Soil amendments	Gypsum (for deeper soil layers)	(++)	0	(+++)	(0)[6]	(0/+)	0	(0/+)	(++)[6]	(+)	(++)	0
Biofertilizers / Biostimulants	N-fixing bacteria (Rhizobia)	(+++)	(+)	0	0	(++)	(+++)	(+)	0	(++/+++)	(+)	0
Biofertilizers / Biostimulants	Free N-fixing bacteria (e.g., Azotobacter)	(++)	(+)	(+)	0	(++)	(++)	(0/+)	0	(++)	(+)	0
Biofertilizers / Biostimulants	Plant teas	(+)	0	0	0	0	(+)	(+)	(+)	(0/+)	(+)	0
Biofertilizers / Biostimulants	P and K-solubizing bacteria (e.g., Enterobacter)	(+++)	(+)	(+)	0	0	(+)	(+++)	(++)	(++)	(+)	0
Biofertilizers / Biostimulants	Mycorrhizal fungi	(+++)	(+)	(+)	(0/+)	0	(+)	(++)	(+)	(+)	(++)	0
Biofertilizers / Biostimulants	Trichoderma	(+)	(+)	(+)	0	0	(+)	(+)	(0/+)	(+/+++)	(++)	0
Tillage	Soil tillage[3]	(+/++)[4]	(+/++)[4]	(+/++)	0	0	(+/++)	(+/++)	(+/++)	(++/+++)	(+/+++)	(–/++)

Legend

(---)	Strong negative effect
(--)	Medium negative effect
(-)	Slight negative effect
0	no effect
(+)	Slight positive effect
(++)	Medium positive effect
(+++)	Strong positive effect

Note: [1]Soil biology: Microorganism activity, biomass and diversity; [2]Soil physics: Bulk density, aggregate stability; Biopores; Water holding capacity; [3]High dependencies on soil tillage system; [4]The lower the intensity the better; [5]Soil pH adjusted by the application of lime can improve soil potassium (K) availability (aggregated K to pH changes is poorly understood); [6] Gypsum is not acid soluble and will not change the soil pH.

System element		Short-term strategy: Nutrients	Short-term strategy: Carbon	Long-term strategy: Nutrients	Long-term strategy: Carbon
Cropping system		Forage / multipurpose legume-based crop rotation, agroforestry and alley cropping			
Soil tillage		According to the soil-crop specific demand			
(Bio-) Fertilizers and soil amendments	In situ	Bio-slurry; vermi-compost	Animal / plant-based compost and mulch material based on leguminous forage, multipurpose and alley crops	Animal / plant-based compost (leguminous forage, multipurpose and alley crops)	Animal / plant-based compost (leguminous forage, multipurpose and alley crops); Biochar
(Bio-) Fertilizers and soil amendments	Ex situ	Poultry manure; Black soldier fly compost; Rhizobia; Mineral fertilizers	Compost with narrow C/N ratio	Compost with narrow C/N; Mineral fertilizers	Compost with wider C/N
(Bio-) Fertilizers and soil amendments		Lime & gypsum according to the soil specific demand			
Phases		Amount of nutrients and carbon			
1. Repair		(++/+++)	(+++)	(+++)	(+++)
2. Maintenance		(+/+++)[a]	(++)	(+/++)	(+/++)

Table 1. Short- and long-term nutrient and soil carbon strategy (Source: own)

Note: a = can be reduced, due to a higher share of nutrients from the soil nutrient stock, enriched over time;
\+ = low amounts
++ = medium amounts
+++ = high amounts

Outlook

- **Relinking carbon inputs with nutrients** is an important aspect of soil health maintenance that has been under invested in.
- **Organic inputs** help to restore the balance of carbon and nutrients, which is crucial for effective nutrient management and crop response (Sommer et al., 2013; Stewart et al., 2020).
- **Organic fertilizers** providing nutrients within shorter time frames should find more consideration as key elements in farming systems (e.g., bioslurry)
- **Internal farm practices**, such as crop rotation, cover crops, alley cropping, composting, animal manure, bioslurry, adjusted soil tillage, and the inclusion of leguminous crops, are essential for balancing soil health and nutrient management.
- **Ex situ organic fertilizers**, including household waste, human feces, and market and agro-processing residues, are valuable sources for composting and bioslurry production, helping to address carbon and nutrient deficiencies (e.g., Freyer et al., 2024; Lenhart et al., 2022; Castro-Herrera et al., 2022).
- **Proper management** of ex situ organic wastes benefits farms and reduces significant environmental and health burdens associated with their current mismanagement in many regions (Tomito et al., 2020).
- **Biofertilizers/biostimulants** (fungus- and bacteria-based / Rhizobia) and **soil amendments** (lime, gypsum, and biochar) can enhance nutrient availability, improve soil characteristics, and boost crop health (Schütz et al., 2018).
- A strategic and thoughtful **use of inorganic fertilizers** can address specific nutrient deficiencies and supply readily available nitrogen, thereby promoting crop yields (Vanlauwe et al., 2023).

References

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