A review of organic inputs to inform soil health advice for African smallholder farmers: localization matters

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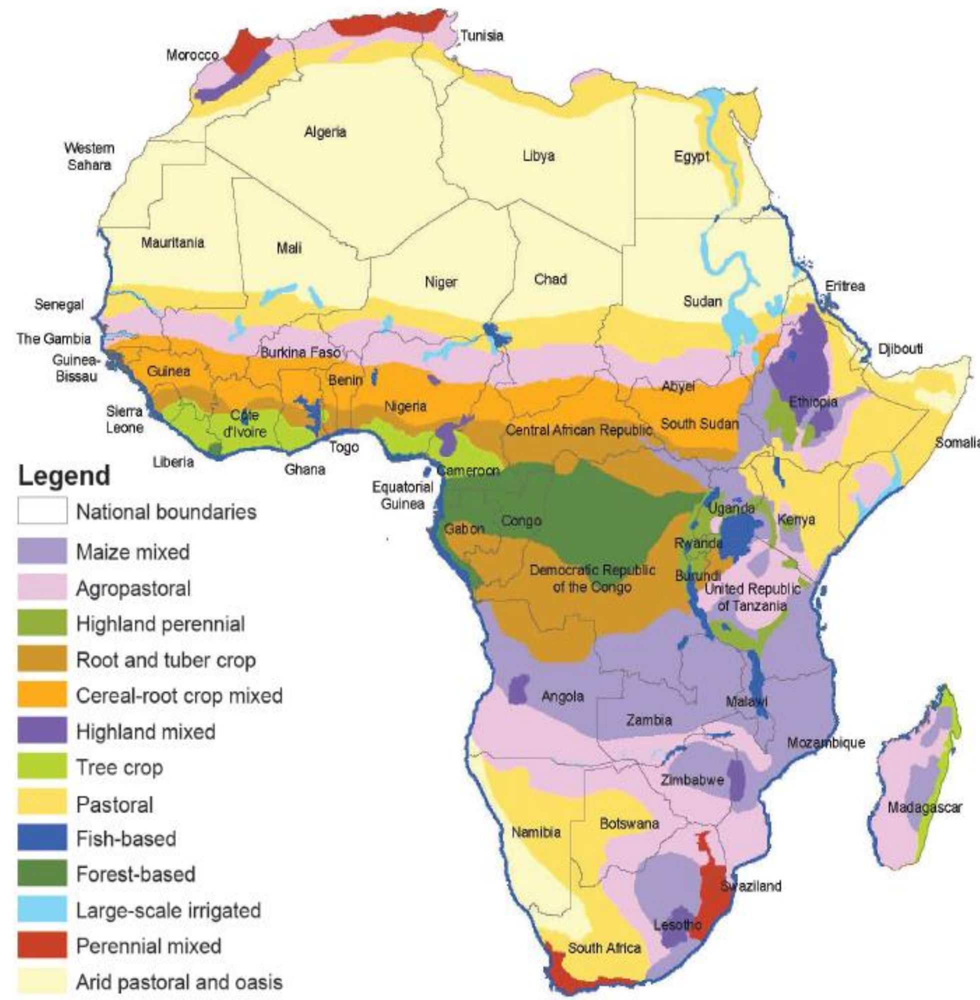
1. Background

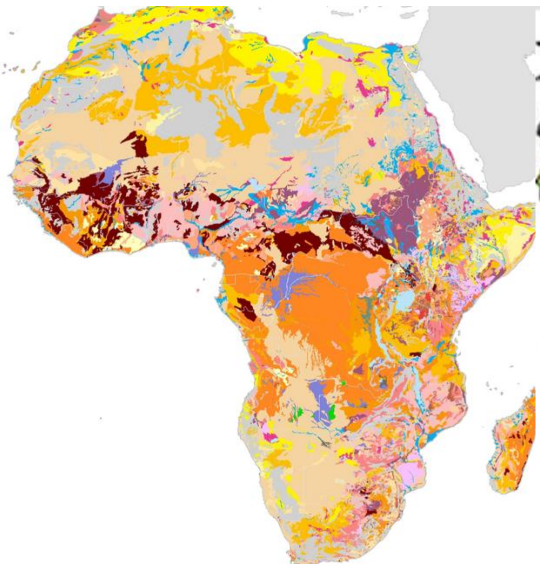
African smallholder farming systems are complex, diverse and locally adapted to:

- ❑ Soils
- ❑ Climate
- ❑ Markets
- ❑ Demography, etc.

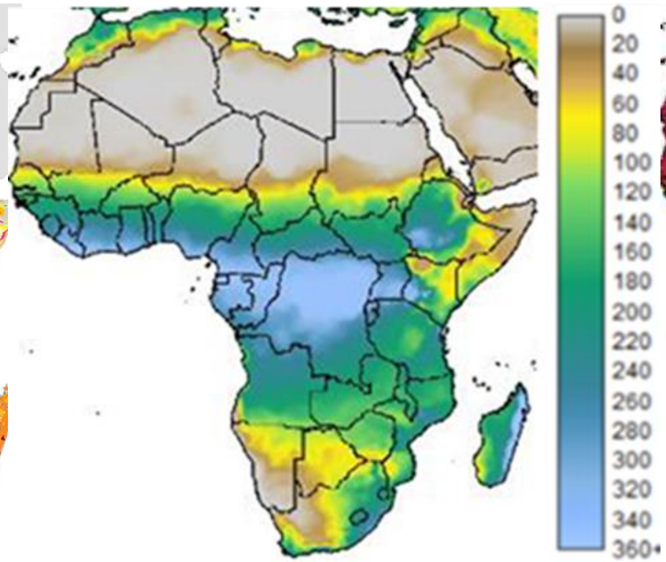


Map of farming systems (Dixon et al., 2020)

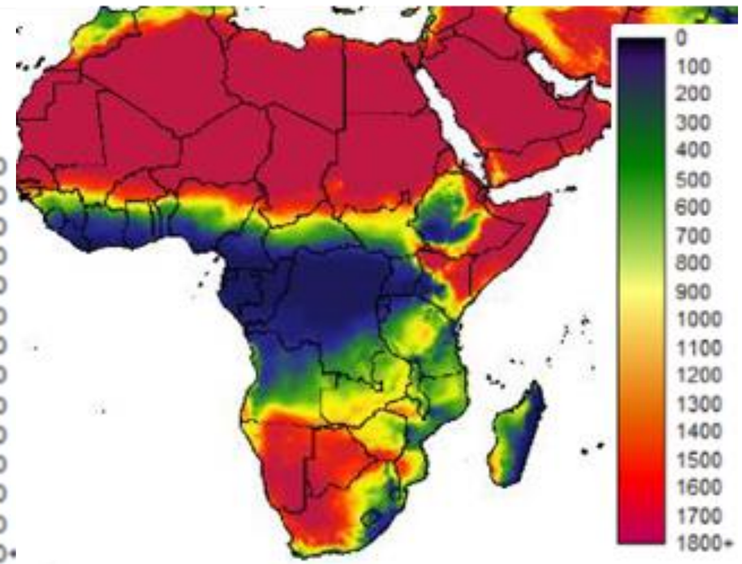
Farmers face a diversity of soil and climatic constraints



Soil type



Length of the growing period (days)



Reference water deficit (mm)

Many of the constraints vary over a short distance

However, experts often make blanket recommendations for inputs

For example, inorganic fertilizer use

- Recommendations are not sufficiently site-specific
- Consist only of nitrogen, phosphorus (and/or potassium), i.e., NP(K)
- Other macronutrients and micronutrients are rarely applied; net **cation loss** drives soil acidification even under optimized NP(K) fertilization
- NP(K) rates recommended to achieve the ecological yield potential are not profitable in many cases.

The economic yield gap is only ~25% of the ecological yield gap for rainfed maize.

The economic yield gap is the difference between current yield and profit-maximizing yield.

Bonilla-Cedrez et al. (2021) *Nature Food* 2: 766. DOI: 10.1038/s43016-021-00370-1

Soil health:

What does it mean?

- It means different things to different people; there are many definitions.
- Soil health is the continued <u>capacity</u> of soil to <u>function</u> as a vital <u>living ecosystem</u> that <u>sustains the biosphere and all life on earth</u>

How is it measured?

- Attributes of a “healthy” soil are complex and context-dependent
- Many frameworks, indicators and indices

Commonly reported soil health problems in Africa

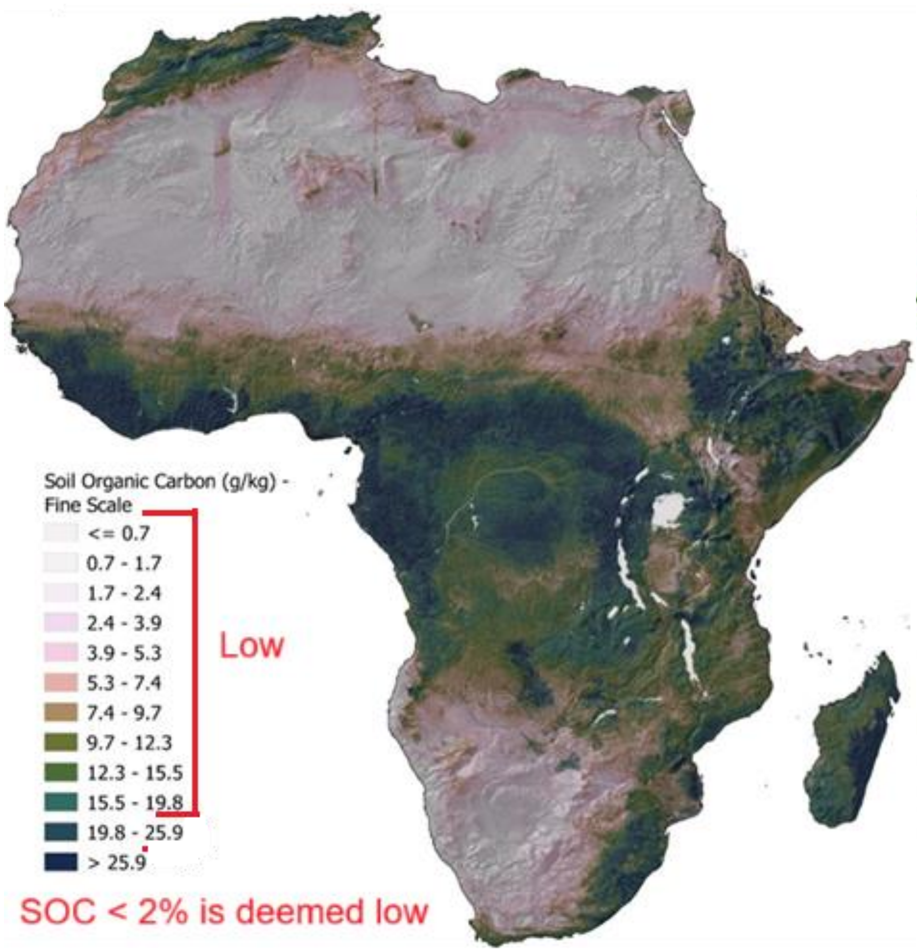
- ❑ Declining soil organic matter (SOM) -- SOC
- ❑ Soil acidity and associated toxicity
- ❑ Nutrient deficiencies
- ❑ Nutrient imbalances (i.e., stoichiometric ratios)

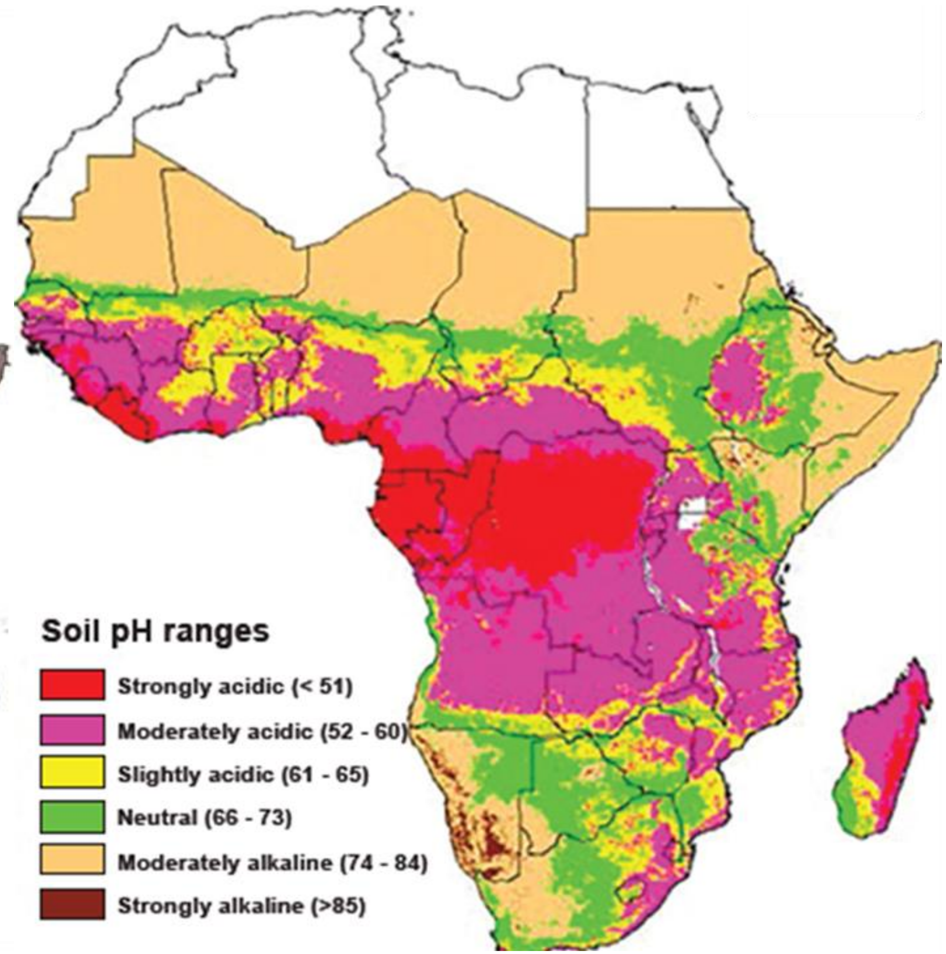
But soil health problems are context-specific, and often related to:

- ❑ Soil type
- ❑ Biota -flora, fauna (e.g., litter transformers, ecosystem engineers), microbiota
- ❑ Climate
- ❑ Topography
- ❑ Anthropogenic factors, e.g., tillage, compaction, input use/abuse, etc.

Extent and magnitude of soil health problems vary widely

e.g., SOC and soil acidity

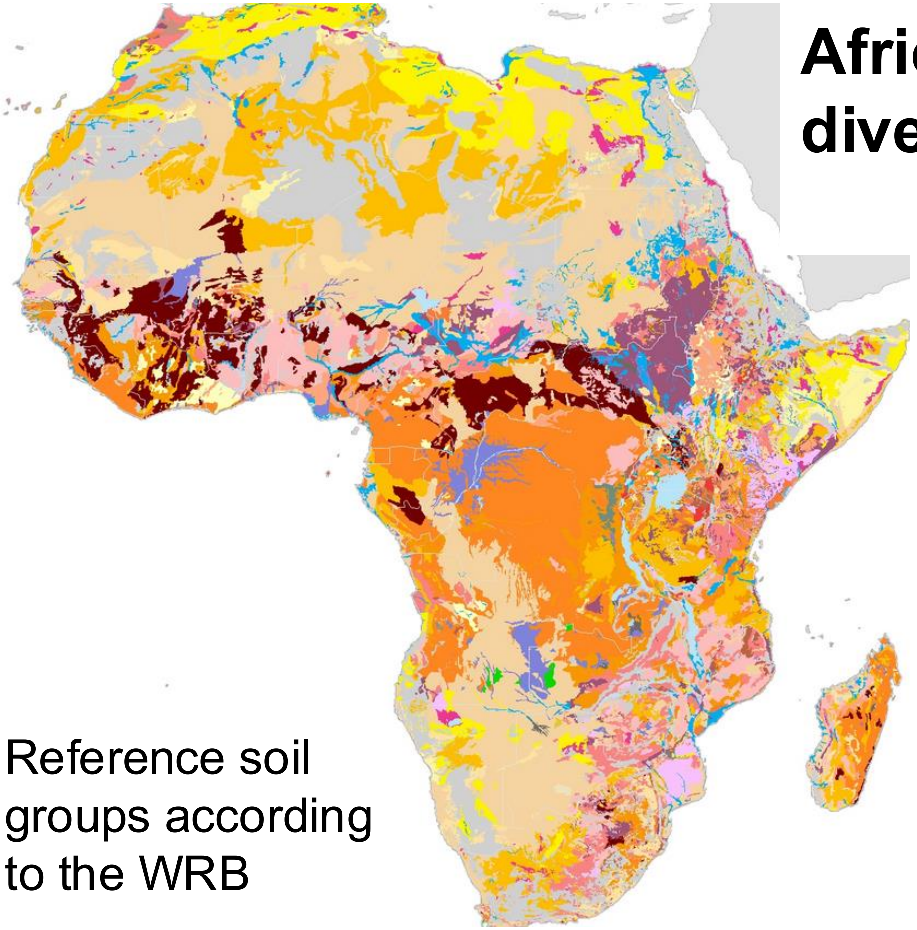




Map of SOC (Kabonye et al., 2024)
DOI: 10.1016/j.scitotenv.2024.175476

Map of soil acidity (Leenaars et al., 2014)

Soil health problems are closely related to soil type



Reference soil groups according to the WRB

African soils have diverse mineralogy

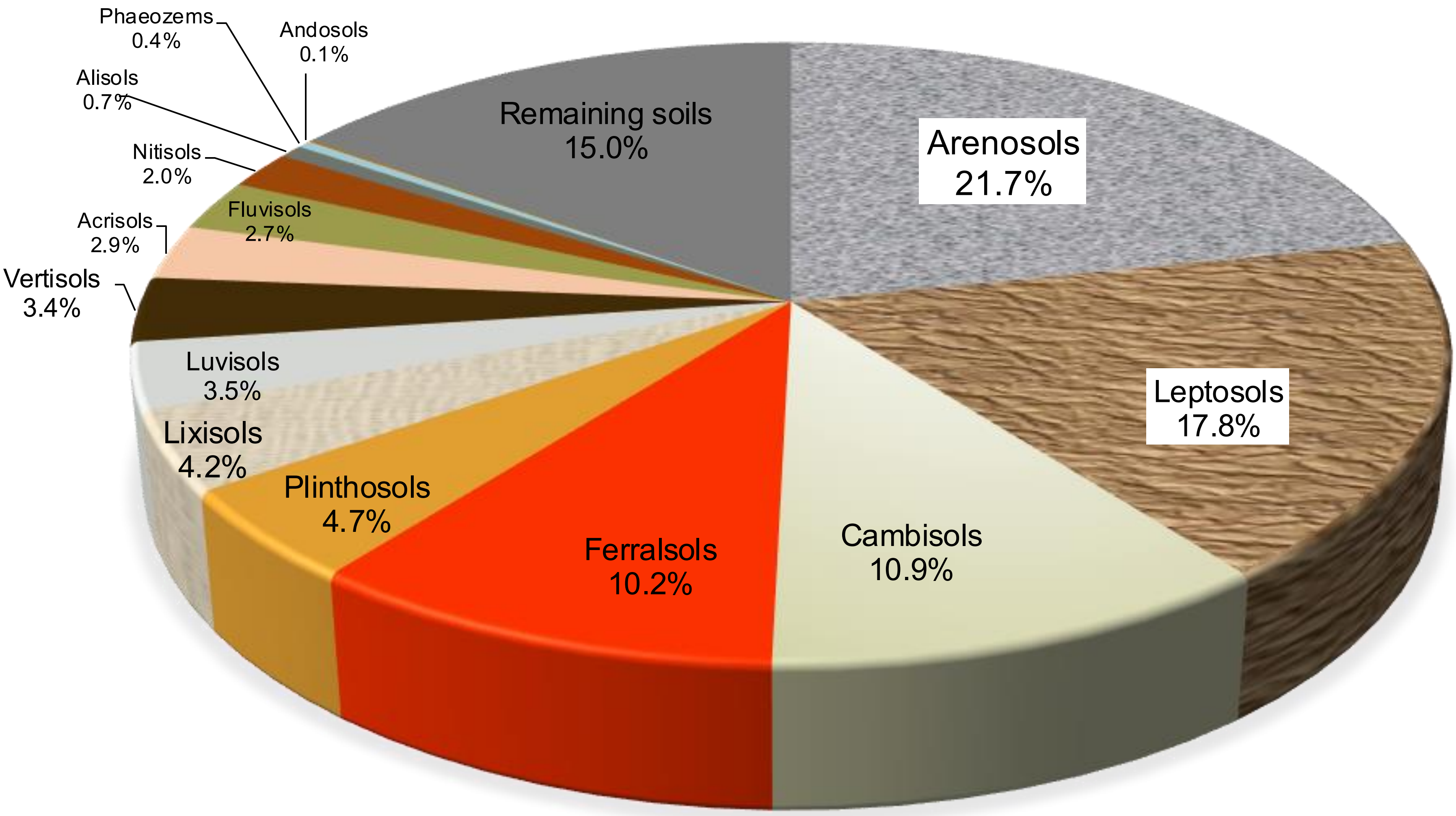
There are 29 well defined reference soil groups

Soil Atlas of Africa (2014)

Unfortunately, the role of soil type on soil health and its ecosystem services is underappreciated

Sileshi (2023) *Geoderma* 439: 116663. DOI: [10.1016/j.geoderma.2023.116663](https://doi.org/10.1016/j.geoderma.2023.116663)

Area of Africa (in %) covered by the different soil types



Sileshi et al. (2022) *Experimental Agriculture* 58: e7. DOI: 10.1017/S0014479721000247

Each soil type has unique constraints, with implications for soil health

Soil	Resilience	SOC	pH	P fixation	Clay activity	CEC
Acrisols	Low	Moderate	Very acidic	Very high	Low	Low
Alisols	Low	Very low	Very acidic	High	High	Low
Andosols	Low	High	Very acidic	Very high	High	High
Arenosols	Low	Very low	Neutral	Low	Low	Very low
Cambisols	High	High	Very acidic	Low	High	Moderate
Ferralsols	High	Low	Very acidic	Very high	Low	Low
Fluvisols	High	High	Slightly acidic	Moderate	High	High
Leptosols	Low	Very low	Neutral	Low	Low	Low
Lixisols	Low	Very low	Neutral	High	Low	Very low
Luvisols	High	Low	Neutral	Low	High	Low
Nitisols	High	High	Slightly acidic	High	Low	Low
Phaeozems	High	Moderate	Slightly acidic	Low	High	High
Plinthosols	Low	--	Slightly acidic	High	Low	Low
Vertisols	High	--	Neutral	Moderate	High	High

These differences are rarely taken in to account when recommending inputs

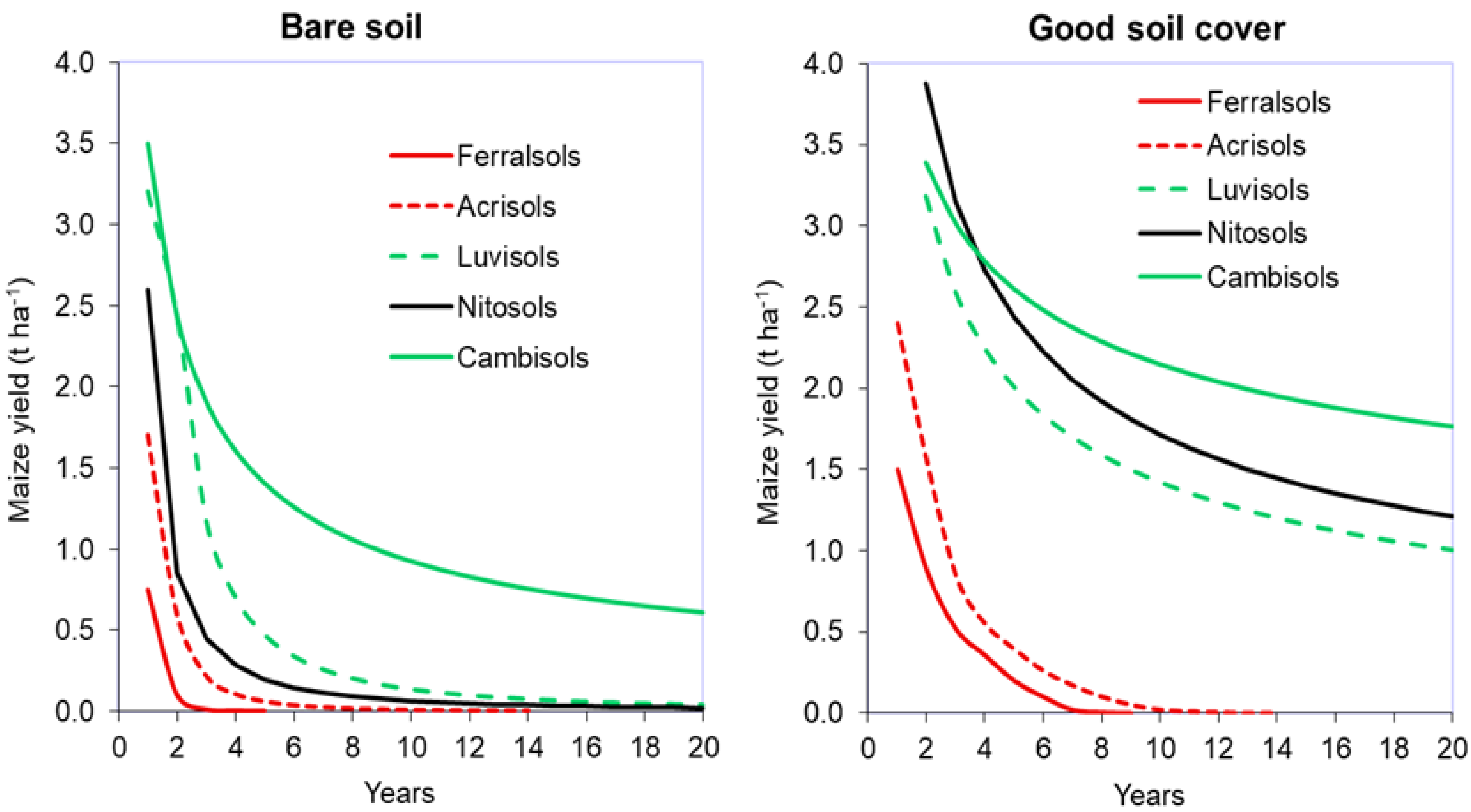
Sileshi et al. (2022) *Experimental Agriculture* 58: e7. DOI: 10.1017/S0014479721000247

Responsiveness of the soils to mineral fertilizers varies widely

Reference soil group	Predicted probability of no response to NPK fertilizer			
	Response ratio ≤1	Agronomic efficiency of N≤0	Agronomic efficiency of P≤0	Agronomic efficiency of K≤0
Plinthosols	0.26	0.24	0.24	0.28
Alisols	0.16	0.15	0.15	0.18
Lixisols	0.16	0.14	0.14	0.16
Leptosols	0.13	0.11	0.11	0.17
Andosols	0.11	0.09	0.09	0.13
Arenosols	0.11	0.10	0.10	0.12
Ferralsols	0.09	0.08	0.08	0.08
Phaeozems	0.08	0.07	0.07	0.16
Vertisols	0.08	0.05	0.05	0.04
Acrisols	0.07	0.07	0.07	0.04
Cambisols	0.05	0.04	0.04	0.06
Luvisols	0.04	0.03	0.03	0.03
Nitisols	0.04	0.04	0.04	0.08
Fluvisols	0.02	0.01	0.01	0.01

Sileshi et al. (2022) *Experimental Agriculture* 58: e7. DOI: 10.1017/S0014479721000247

Crop yields decline faster on some soils than others when cultivated



Scenarios of maize yield decline over time

Sileshi et al. (2010) *Field Crops Research* 16: 1-13. DOI: [10.1016/j.fcr.2009.11.014](10.1016/j.fcr.2009.11.014)

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Organic inputs can address some of the soil health problems

But

- Availability of organic inputs depends on the farming system & household endowment
- Many competing uses for organic inputs, for example
  - Crop residues: animal feed, fuel, construction, bioenergy, etc.
  - Manure: fuel, construction, bioenergy, etc.
- Farmers face multiple decision points in the choice of organic inputs
- Guidance is lacking on the types and quantities of organic inputs and crop diversification options

2. Methods

We reviewed existing meta-analyses and performed additional meta-analyses to answer the following questions

1) What are the options available to African smallholder farmers?
2) What are the benefits and farmers' production constraints that could be addressed using these inputs?
3) In what contexts are the soil health and productivity gains greatest?
4) What decision-support tools are needed to guide hyper-localization of organic inputs?

For inferences, we used the median (representing **expected value**) and its 95% confidence interval (representing the **uncertainty**) estimated using accelerated and bias-corrected bootstrapping.

We used the following indicators for quantitative analysis/meta-analysis

1. Productivity indicators: crop yield (weight of grains, seeds, leaves, roots, etc., on dry or fresh biomass depending on crop)

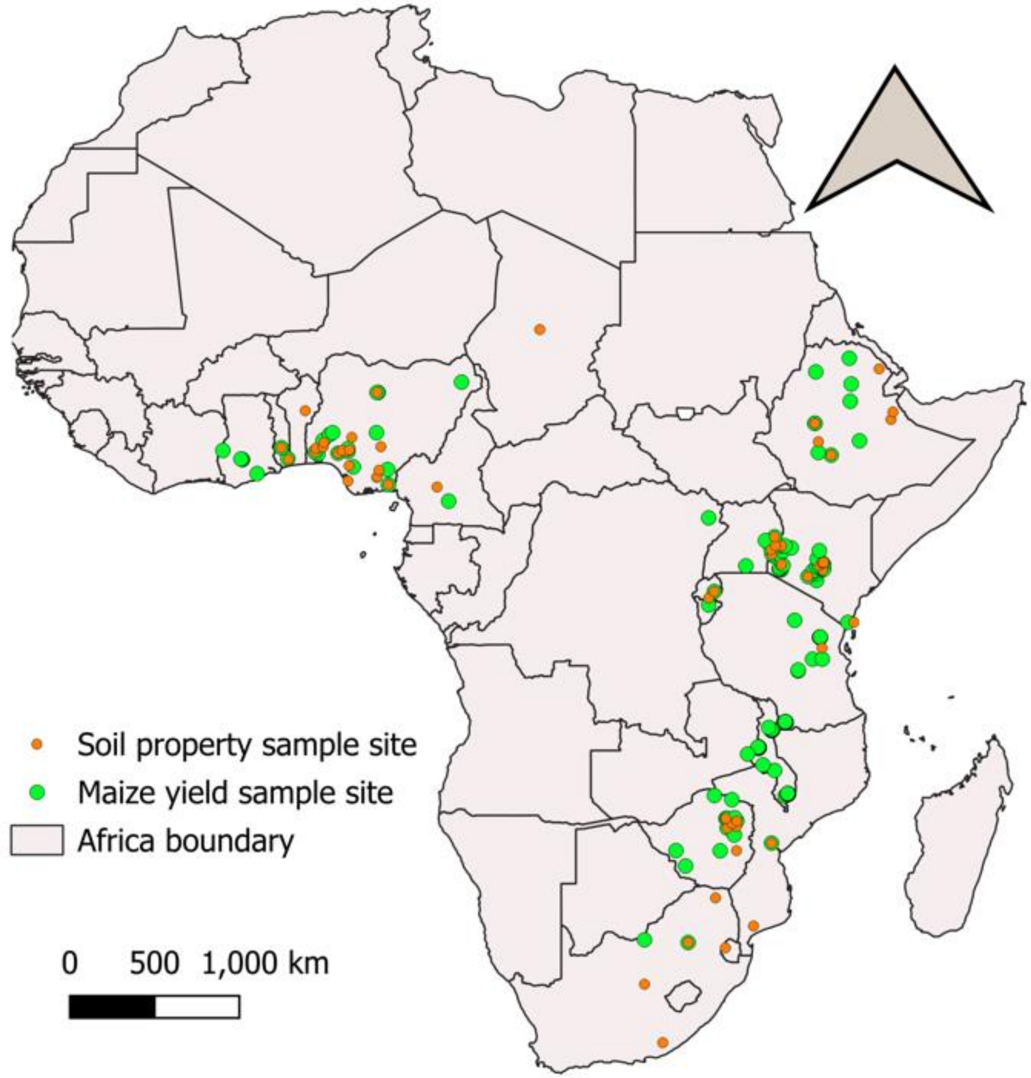
2. Soil health indicators: Bulk density, pH, soil organic carbon (SOC), total nitrogen (N), available phosphorus (P), exchangeable cations (Ca, Mg).

We chose indicators used by current soil health assessment frameworks

Lehmann et al., 2020; Nat. Rev. Earth Environ. 1: 544. DOI: 10.1038/s43017-020-0080-8

In meta-analysis we are not interested in statistical significance, but in estimating the **effect size** (i.e., the **magnitude of change**) because that is the **policy-relevant information**

Soil properties and crop yield data reported by the primary studies used in the meta-analysis came from:



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In the meta-analysis, we compared organic inputs and the recommended synthetic fertilizer in terms of:

- % changes in crop yields relative to the **no-input control** (*de facto* poor farmers' practice)

$$\%change = 100 * \left(\frac{Treatment - Control}{Control}\right) = 100 \times (RR - 1)$$

Where RR is the response ratio = Treatment/Control

- % changes in soil health indicators relative to the baseline (time 0):

$$\%change = 100 * \left(\frac{Treatment - Baseline}{Baseline}\right)$$

Input categories:

Ex-situ inputs: inputs brought from other fields, farms or the market

In-situ inputs: inputs produced in the same field where they are applied

3. Our findings

3.1. Options available to farmers and evidence for benefits

Input/ approach	Options	Meta-analyses/systematic reviews
Ex situ	Livestock manure	Sileshi et al., 2017; 2018; 2024
	Tree biomass (biomass transfer)	Sileshi et al., 2025
	Compost	Sileshi et al., 2025
	Anaerobic digestate	No studies in Africa
	Biochar	Very few studies in Africa
In situ	Crop residue retention	Chivenge et al., 2011 Sileshi et al., 2025
	Intercropping with food legumes	Kuyah et al., 2023; 2021 Himmelstein et al., 2017
	Rotation: food legumes	Kuyah et al., 2023; 2021
	Rotation: green manures legumes	Sileshi et al., 2008; 2010
	Agroforestry: Intercropping	Sileshi et al., 2008; 2010 Muchane et al., 2022
	Agroforestry: Rotations	Sileshi et al., 2008; 2010 Muchane et al., 2022

3.2. Benefits and farmers production constraints addressed

Input/approach	Soil health constraint addressed	Farmers' constraints addressed
Ex situ		
Livestock manure and compost	Soil acidity; declining SOM; nutrient deficiencies; nutrient imbalances; Al and Fe toxicity; poor soil water content/permeability	Declining crop productivity; lack of cash to buy synthetic fertilizers
Biomass transfer (agroforestry)	Declining SOM; nutrient deficiencies; nutrient imbalances; poor soil water content/permeability	Declining productivity; shortage of livestock fodder
In situ		
Crop residue retention	Soil erosion; soil acidity; declining SOM, reduction in temperature, reduced evapotranspiration, poor water infiltration	Declining crop productivity; loss of topsoil, heat and drought stress
Intercropping with grain legumes	Declining SOM; N deficiencies; pest and diseases build up; poor water infiltration	Declining landholding size; declining crop productivity; dietary deficiencies; weed problems; poor food nutrient diversity
Rotation with grain legumes	Declining SOM; N deficiencies; soil-borne diseases; pest and diseases build up; poor water infiltration	Declining productivity; dietary deficiencies; shortage of protein-rich food; weed problems; poor food nutrient diversity
Rotation with green manures legumes	Declining SOM; nutrient deficiencies; nutrient imbalances; pest build up; soil borne diseases; poor water infiltration	Declining productivity; weed problems
Agroforestry: Intercropping	Declining SOM; nutrient deficiencies; nutrient imbalances; soil acidity; pest and diseases build up; poor water infiltration	Declining productivity; lack of cash to buy fertilizers; weed problems; poor food nutrient diversity
Agroforestry: Rotations	Declining SOM; nutrient deficiencies; nutrient imbalances; pest and diseases build up; soil acidity	Declining productivity; shortage of fuel wood; shortage of livestock fodder; weed problems

Do farmers really adopt these inputs/practices?

Example: Insights from adoption studies on manure

- Adoption rates of livestock manure (median: **52%; CI: 45–66%**) are as high as adoption rates of synthetic fertilizers (median: **60%; CI: 54–76%**)
- Adoption of manure **is conditional** on the adoption of synthetic fertilizers, improved seeds and soil and water conservation practices
- Lack of information on manure management, composting and application (placement, rate, timing) constrain adoption of manure

Sileshi et al. (2025) *Agric Ecosyst Environ* **379**: 109347. DOI: 10.1016/j.agee.2024.109347

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How much is the expected improvement in soil health indicators?

In the short-term (1-3 years)

	Medians (and 95% CI) % change relative to baseline			
Indicators [# of studies, N]	No-input control	Manure‡	Manure + NP(K)	Recommended NP(K) fertilizer
Bulk density [14, 123]	0.3 (0.3, 4.3)	**-12.6 (-16.8, -9.8)**	-2.6 (-3.5, -1.5)	-2.1 (-3.4, -0.7)
Soil pH [43, 525]	0	3.0 (1.7, 4.8)	3.4 (2.0, 5.1)	-1.8 (-2.8, 0)
SOC [47, 558]	-6.6 (-9.6, -0.7)	29.2 (21.7, 35.8)	29.6 (20.6, 46.5)	-1.0 (-3.9, 4.1)
Total N [44, 463]	-11.4 (-17.9, 0)	21.1 (8.5, 28.6)	18.9 (13.3, 35.3)	3.1 (0, 8.3)
Available P [44, 538]	-3.7 (-9.3, 0)	55.4 (40.9, 68.0)	60.3 (38.2, 89.9)	35.7 (24.9, 59.9)
Ex. K [39, 414]	-7.4 (-17.4, 0)	40.0 (26.1, 64.2)	**79.3 (65.5, 100)**	0 (0, 26.1)
Ex. Ca [29, 332]	-3.3 (-10.8, 0)	20.6 (11.1, 28.6)	12.5 (3.4, 21.7)	-3.0 (-11.5, 5.2)
Ex. Mg [31, 352]	-7.5 (-11.4, 0)	24.4 (19.5, 37.5)	30.0 (26.0, 64.2)	-6.9 (-11.1, 0)
CEC [6, 66]	-1.8 (-4.5, 6.2)	16.0 (2.4, 35.3)	15.4 (6.4, 22.2)	0 (-3.6, 10.2)

Take-home message

- ✓ Manure alone or manure + synthetic fertilizer achieves greater soil health improvement than the recommended synthetic fertilizer
- ✓ The *de facto* poor farmers' practice (no-input) results in deterioration of soil health indicators

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

How much is the expected gain in crop yields?

	Medians (and 95% CI) % change relative to a no-input control		
Crop [# studies, N]	**Manure**	**Manure + NP(K)**	**Recomm. NP(K)**
Maize [85, 2116]	75.4 (64.4–84.9)	**129.1 (114.7–146.2)**	91.6 (79.2–104.8)
Other cereals [17, 268]	35.6 (21.5–50.0)	38.1 (28.2–70.7)	53.6 (19.5–123.6)
Grain legumes [11, 153]	12.3 (3.8–25.1)	**139.3 (74.4–229.9)**	24.7 (15.1–59.5)
Leafy vegetables [21, 240]	41.0 (31.7–55.3)	**113.6 (88.9–151.2)**	47.0 (20.0–174.7)
Roots and tubers [17, 233]	53.8 (46.1–69.6)	**80.8 (63.0–104.1)**	46.2 (36.7–60.0)
Fruity vegetables [10, 126]	38.4 (29.4–56.9)	43.1 (26.5–65.0)	NA
Cucurbits [4, 56]	51.7 (45.4–188.5)	66.2 (64.7–69.3)	65.5 (60.5–75.2)
Bulbs [3, 19]	147.6 (97.6–233.8)	**705.1 (705.1–875.2)**	485 (485–633)

Green cells indicate statistically significant gain relative to the other inputs in a raw

Take-home message:

- ✓ Most crops show greater response to manure + NP(K) fertilizer than manure alone or the recommended synthetic fertilizer
- ✓ Partial substitution of synthetic fertilizer with manure is preferable

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

3.3. In what contexts are soil health benefits and productivity gains greatest?

Example: Changes (in %) in maize yield relative to a no-input control (medians & 95% CI)

		Ex-situ inputs			In-situ inputs
Moderator	**Category**	**Manure**	**Biomass transfer**	**NP(K) fertilizer**	**Crop residue**
MAP (mm)	>1000	**93 (81, 113)**	**120 (94, 183)**	94 (63, 119)	**17 (10, 32)**
	600-1000	67 (50, 100)	27 (19, 47)	92 (79, 111)	-14 (-30, -4)
	<600	47 (31, 77)	18 (-35, 356)	68 (52, 119)	-3 (-65, 89)
Soil texture	Clayey	64 (53, 87)	**131 (83, 187)**	79 (60, 92)	15 (8, 38)
	Loamy	42 (32, 60)	50 (33, 82)	110 (65, 133)	-7 (-19, 15)
	Sandy	**104 (81, 126)**	50 (21, 100)	78 (60, 118)	-16 (-31, 43)
Soil pH	<5.5	86 (64, 103)	--	91 (66, 110)	--
	5.5-6.5	**97 (73, 126)**	--	104 (81, 121)	--
	>6.5	28 (23, 70)	--	66 (55, 94)	--
SOC initial	<1%	51 (43, 64)	65 (45, 99)	63 (47, 84)	**30 (22, 85)**
	1-2%	**154 (117, 207)**	**133 (83, 191)**	113 (82, 140)	-14 (-27, 2)
	>2%	74 (56, 91)	68 (35, 104)	108 (77, 123)	-11 (-31, 0)

Green cells indicate statistically significant gain relative to the other inputs in a raw

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

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Where do greater maize yield increases occur with legume diversification?

		Median (95% CI) % change relative to a no-input control	
Moderators	**Category**	**Grain legumes**	**Green manures**
MAP (mm)	>1000	29 (18, 37)	**80 (68, 91)**
	600-1000	19 (15, 28)	42 (25, 54)
	<600	17 (12, 24)	--
Soil texture	Fine	24 (16, 34)	51 (25, 69)
	Medium	**32 (20, 48)**	**95 (84, 115)**
	Coarse	15 (11, 23)	50 (43, 61)
Soil pH	<5.5	16 (13, 20)	59 (38, 75)
	5.5-6.5	**29 (19, 36)**	64 (56, 71)
SOC initial	<1	20 (16, 28)	40 (31, 57)
	1-2	19 (11, 35)	**106 (86, 114)**
	>2	25 (15, 36)	51 (39, 62)
Total N (in %)	<0.15	18 (13, 21)	44 (33, 60)
	>0.15	**38 (30, 53)**	**74 (63, 87)**

Green cells indicate statistically significant improvement relative to the other inputs in a raw

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

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Where do greater improvements in soil health occur with sole manure?

		Changes (in%) relative to the baseline			
Moderator	Category	pH	SOC	Total N	Available P
MAP (in mm)	>1000	-1 (-3, 2)	52 (26, 100)	**33 (33, 100)**	88 (31, 280)
	600-1000	**6 (4, 12)**	11 (5, 31)	2 (-7, 22)	**119 (74, 206)**
	<600	3 (2, 7)	30 (21, 36)	7 (0, 21)	41 (32, 56)
Soil texture	Clayey	4 (-5, 6)	27 (3, 58)	-28 (-38, -7)	38 (-29, 467)
	Loamy	1 (1, 12)	62 (29, 139)	-24 (-64, 30)	**130 (84, 214)**
	Sandy	3 (2, 6)	33 (25, 39)	**21 (15, 33)**	49 (30, 61)
pH	<5.5	**9 (6, 11)**	22 (13, 55)	12 (-4, 29)	49 (32, 59)
	5.5-6.5	2 (2, 4)	32 (22, 36)	15 (1, 25)	69 (54, 105)
	6.5-7.5	1 (-2, 9)	40 (27, 64)	**33 (28, 93)**	25 (6, 47)
SOC initial	<1%	2 (1, 5)	**49 (38, 61)**	0 (0, 45)	56 (37, 80)
	1-2%	7 (4, 9)	22 (16, 29)	21 (10, 29)	**59 (47, 79)**
	>2%	1 (-1, 3)	-4 (-10, 3)	104 (30, 118)	18 (8, 32)

Green cells indicate statistically significant improvement relative to the other inputs in a raw

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

Where do greater improvements in soil health occur with manure + NP(K)?

Moderator	Category	Changes (in%) relative to the baseline			
		pH	SOC	Total N	Available P
MAP	>1000	1 (-1, 6)	45 (-14, 123)	--	30 (4, 123)
	600-1000	5 (2, 10)	32 (15, 92)	**25 (25, 42)**	5 (-3, 74)
	<600	2 (2, 4)	25 (14, 36)	4 (0, 19)	71 (40, 145)
Soil texture	Clayey	3 (3, 10)	19 (8, 53)	2 (-9, 40)	-2 (-21, 6)
	Loamy	8 (2, 15)	**73 (56, 123)**	38 (21, 65)	**105 (86, 205)**
	Sandy	2 (1, 4)	30 (21, 46)	16 (2, 25)	**65 (42, 138)**
pH	<5.5	6 (5, 10)	28 (19, 48)	19 (17, 41)	84 (44, 142)
	5.5-6.5	2 (0, 3)	25 (8, 45)	4 (0, 25)	42 (22, 129)
	6.5-7.5	**11 (9, 14)**	47 (18, 85)	25 (25, 125)	60 (32, 98)
SOC initial	<1%	0 (-1, 3)	47 (31, 54)	8 (0, 26)	37 (24, 56)
	1-2%	6 (4, 7)	13 (3, 28)	17 (13, 25)	**182 (60, 325)**
	>2%	7 (3, 11)	6 (5, 48)	2 (-8, 39)	87 (4, 184)

Green cells indicate statistically significant improvement relative to the other inputs in a raw

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

Where do greater improvements in agronomic efficiency of nitrogen (AEN) occur?

Moderator	Category	Manure	Manure + NP(K)	Recommended NP(K)
MAP (mm)	>1000	11 (9, 13)	**14 (13, 15)**	**24 (21, 30)**
	600-1000	9 (6, 13)	9 (8, 11)	10 (9, 12)
	<600	2 (2, 11)	7 (7, 16)	10 (8, 19)
Soil texture	Clayey	**14 (9, 17)**	12 (10, 14)	11 (9, 15)
	Loamy	8 (4, 12)	11 (10, 15)	15 (13, 23)
	Sandy	7 (6, 8))	8 (8, 10)	11 (9, 16)
Soil pH	<5.5	**12 (10, 15)**	12 (11, 14)	13 (10, 15)
	5.5-6.5	7 (6, 10)	9 (8, 11)	13 (10, 16)
	6.6-7.5	7 (4, 14)	15 (8, 20)	13 (8, 17)
	>7.5	6 (4, 22)	--	--
SOC (% initial)	>2%	10 (9, 14)	11 (9, 13)	13 (10, 18)
	1-2%	**20 (15, 25)**	13 (10, 16)	15 (13, 18)
	<1%	6 (5, 8)	10 (9, 12)	12 (10, 17)

Green cells indicate statistically significant improvement relative to the other inputs in a raw

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

What is the right placement method?

Changes in cereal yields (in % relative to no-input control), rain use efficiency (RUE), agronomic efficiency of nitrogen (AEN) and phosphorus (AEP), and benefit cost ratios (BCR) with placement method

		Medians (and 95% CI)				
	Placement	Cereal yield	RUE	AEN	AEP	BCR
Manure	Spot-applied	94 (58–138)	3.0 (2.2–4.0)	15.0 (10.1–19.9)	46 (28.7–63.2)	3.3 (1.8–6.0)
	Banded	78 (35–133)	2.4 (1.4–4.0)	14.1 (7.9–20.3)	44.5 (24.0–65.0)	4.8 (2.8–8.2)
	Broadcast	94 (69–124)	2.4 (1.9–3.0)	11.0 (7.7–14.4)	34.9 (23.5–46.4)	3.6 (2.1–6.2)
Manure + NP(K)	Spot-applied	147 (103–201)	3.5 (2.6–4.6)	16.9 (12.3–21.6)	44.9 (28.8–61.1)	7.6 (3.8–15.2)
	Banded	157 (94–240)	2.3 (1.4–3.7)	16.7 (10.1–23.2)	43.5 (22.0–64.9)	3.3 (1.8–6.1)
	Broadcast	198 (159–244)	3.7 (3.0–4.5)	15.0 (11.6–18.3)	34.4 (23.2–45.7)	4.5 (2.6–7.6)
Recomm. NP(K)	Spot-applied	110 (70–159)	3.0 (2.2–4.0)	**27.5 (22.4–32.6)**	**72.4 (54.6–90.2)**	**11.7 (5.8–23.5)**
	Banded	96 (46–163)	2.4 (1.5–3.8)	19.6 (12.7–26.4)	37.1 (14.5–59.6)	3.5 (2.0–6.1)
	Broadcast	134 (100–174)	2.9 (2.3–3.6)	16.6 (13.1–20.2)	38.1 (25.7–50.6)	3.0 (1.8–5.2)

Take-home message: Spot-application and banding

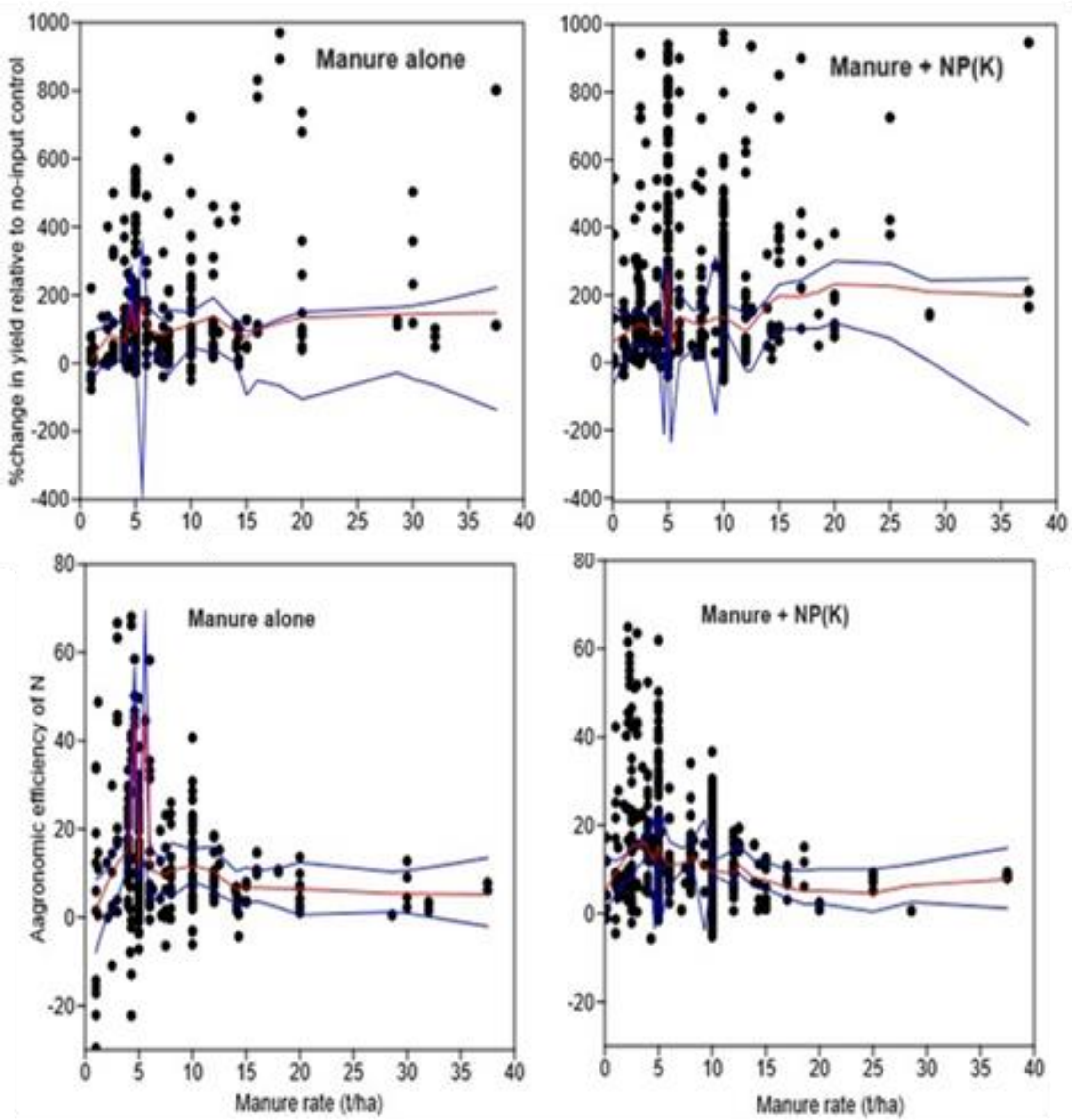
✓ achieve better use of the limited rainfall and applied nutrients

✓ reduce the amount of manure needed, but equally profitable with broadcasting

Sileshi et al. (2025) *Agric Ecosyst Environ* **379**: 109347. DOI: 10.1016/j.agee.2024.109347

What is the right manure application rate?

LOESS (locally estimated scatter plot) regression



Take-home message

- ✓ Sole manure rates >5 t/ha do not achieve further improvements in maize yields
- ✓ Rates up to 15 t/ha slightly increase yield response with manure + synthetic fertilizer
- ✓ But agronomic efficiency of N decreases with increasing manure rates exceeding 5 t/ha

3.5. What decision-support tools are needed to guide hyper-localization of organic inputs?

Our results highlight the need for hyper-localization of advice on *in situ* and *ex situ* organic inputs.

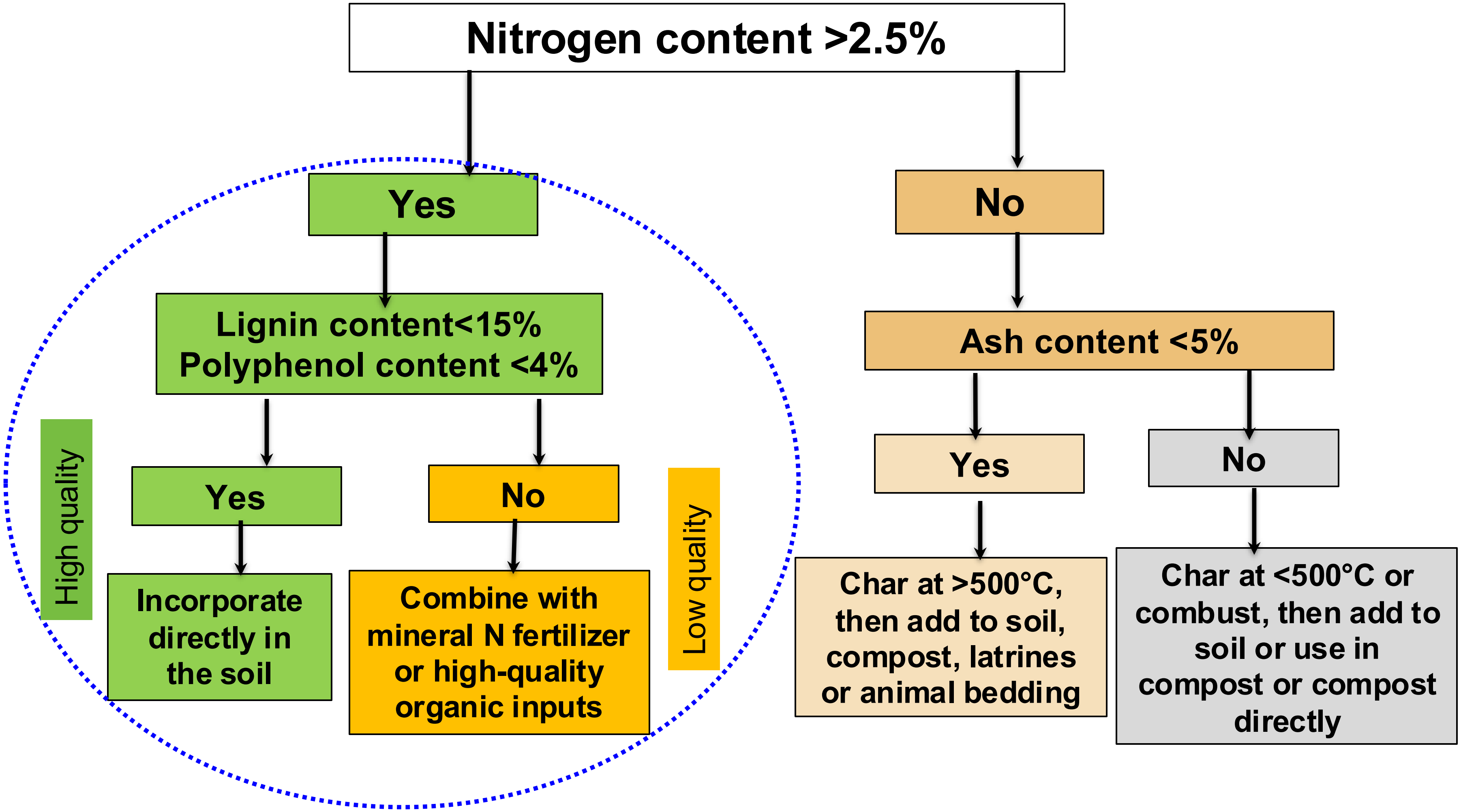
Hyper-localization is the combined use of geospatially interpolated (space-to-place) information with farmer's knowledge and field inputs.

In the case of synthetic fertilizers, decision support tools exist for optimization of nutrient use. Such tools do not exist for organic inputs, which are heterogeneous in terms of their nutrient profiles

The systems and tools needed

- ❑ Decision-support systems for selecting the right organic inputs
- ❑ Rapid soil health diagnosis
- ❑ Extension and digital advisory

Decision-support system (DSS) for on-farm use of organic inputs



Palm et al. (2001), Vanlawue et al. (2002) and Blhum and Lehmann (2024)

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The quality of organic inputs varies widely; hence the need for refinement of the existing decision support system

	Median C and nutrient concentration (% DM)				Stoichiometric ratios	
Residue source [Studies]	Carbon	Nitrogen	Phosphorus	Potassium	C:N	N:P
Cattle manure [119]	27.7	1.2	0.33	1.28	21.1	3.6
Goat manure [32]	26.8	1.9	0.31	1.15	16.3	5.3
Sheep manure [9]	27.7	1.9	0.29	**2.27**	15.0	4.6
Poultry manure [68]	28.3	2.2	**1.25**	1.30	13.0	2.1
Swine manure [10]	28.5	1.9	**0.80**	1.09	18.0	2.3
Grain legume straw [3]	34.7	1.7	0.16	--	18.8	**16.0**
Green manure straw [7]	39.8	**2.8**	0.36	--	12.3	**7.6**
Woody legume pruning [14]	**43.8**	**3.2**	0.16	--	13.6	**20.0**
Non-legume pruning [11]	**40.7**	**3.2**	0.20	--	12.3	**15.0**
Cereal straw [10]	**41.4**	0.8	0.10	--	51.4	**9.0**

N-limited

Sileshi et al. (2025) *npj Sustainable Agriculture* 3:20. DOI: 10.1038/s44264-025-00063-3

Livestock manure is highly variable in its nitrogen, lignin and polyphenol contents, and thus could not be easily placed in any of the classes used in the current DSS.

- ✓ Cattle manure is low in nitrogen (N). Therefore, it should be supplemented with N fertilizer to raise the N:P ratio to >6:1
- ✓ Livestock manure supplies adequate P and K; Therefore, combining livestock manure with P and K fertilizers should be discontinued if the manure rate used is >5 t/ha
- ✓ Soil application of **5 ton/ha** dry cattle manure supplies **~60 kg/ha N**, **~17 kg/ha P** and **~64 kg/ha K**. If synthetic P fertilizer is added to this, the N:P ratio will be too low resulting in nutrient imbalances and lower crop yields
- ✓ Need for inclusion of a module for different species of livestock and manure management outcomes in the DSS

The source of manure has implications for crop yield and soil health indicators

	Medians (and 95% CI) % change relative to no-input the baseline (in 1-3 years)	
Variable	Ruminant manure	Nonruminant manure
Maize yield	70.8 (59.1, 82.0)	**130.5 (110.8, 181.5)**
Soil bulk density	-9.4 (-18.9, -1.2)	-15.1 (-16.8, -11.7)
Soil pH	1.7 (1.2, 2.8)	**7.3 (4.2, 9.0)**
SOC	26.8 (14.1, 33.5)	27.8 (19.4, 45.8)
Soil total N	7.5 (0.0, 25.0)	**23.9 (15.4, 57.1)**
Soil available P	37.6 (22.2, 63.8)	60.0 (50.0, 108.6)
Soil exchangeable K	**60.0 (33.3, 100.0)**	24.8 (10.0, 42.7)
Soil exchangeable Ca	3.2 (-3.9, 21.4)	**32.7 (25.0, 62.7)**
Soil exchangeable Mg	7.4 (-5.0, 22.5)	**28.1 (19.2, 45.9)**

Raw manure or compost?

Changes (in %) in maize yields relative to the no-input control

Treatment [study; N]	Median (95% CI)
Raw manure [67; 417]	72 (62, 82)
Compost [16; 96]	78 (52, 100)
Recommended NP(K) [58; 488]	87 (76, 101)
Raw manure + NP(K) [51; 448]	**107 (94, 124)**
Compost + NP(K) [7; 70]	**150 (101, 198)**

Raw manure = fresh or farmyard manure

Nutrient concentrations vary with manure management
For example, cattle manure

	Median concentrations (% dry matter)		
Variable [# studies]	Fresh manure	Farmyard manure	Composted
Carbon [121]	**31.7 (29.0, 34.6)**	27.1 (25.5, 29.0)	22.2 (20.1, 23.3)
Nitrogen [178]	**1.70 (1.58, 1.85)**	1.35 (1.30, 1.43)	1.40 (1.10, 1.69)
Phosphorus [158]	**0.53 (0.49, 0.75)**	0.40 (0.42, 0.46)	0.30 (0.26, 0.40)
Potassium [143]	**1.50 (1.42, 1.80)**	1.21 (1.10, 1.40)	0.62 (0.49, 0.94)
Calcium [90]	0.96 (0.58, 1.28)	**1.05 (0.86, 1.15)**	0.75 (0.36, 0.99)
Magnesium [88]	0.51 (0.35, 0.69)	0.39 (0.36, 0.43)	0.38 (0.18, 0.88)
C:N [119]	19.2 (16.3, 22.0)	19.6 (18.2, 20.6)	15.2 (11.3, 19.6)
N:P [153]	2.9 (2.5, 4.0)	3.6 (3.3, 4.0)	3.8 (3.3, 5.0)

Take-home messages

- ✓ Although fresh manure has higher carbon and nutrient concentrations, composting increases the N:P ratio
- ✓ Composting also makes manure safer and easier to store, transport and apply

Rapid soil health diagnosis + digital advisory

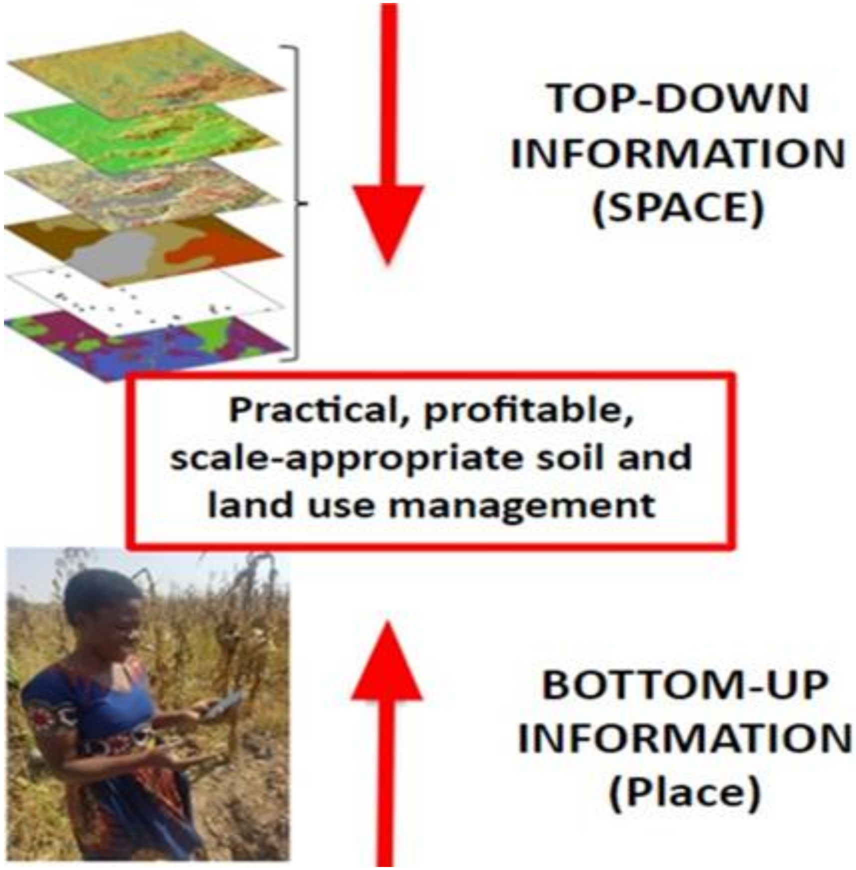
Advancements in sensors, autonomous vehicles, data analytics, predictive modelling, and internet of things are making it easier to provide diagnosis of soil health in real time

The **infological approach** proposed by Cesco provides a good framework for site-specific decision

Infological approach

Cesco et al. (2023) *Eur J Agron* 146: 126809. DOI: 10.1016/j.eja.2023.126809

- ❑ Greater use of the Soil Atlas of Africa + spatially-explicit data on SOC† and other soil properties‡
- ❑ Adopt **farmer-centric on-farm experimentation**§ to gain farmer-relevant insights to guid decision-making
- ❑ Greater use of farmers' indigenous knowledge



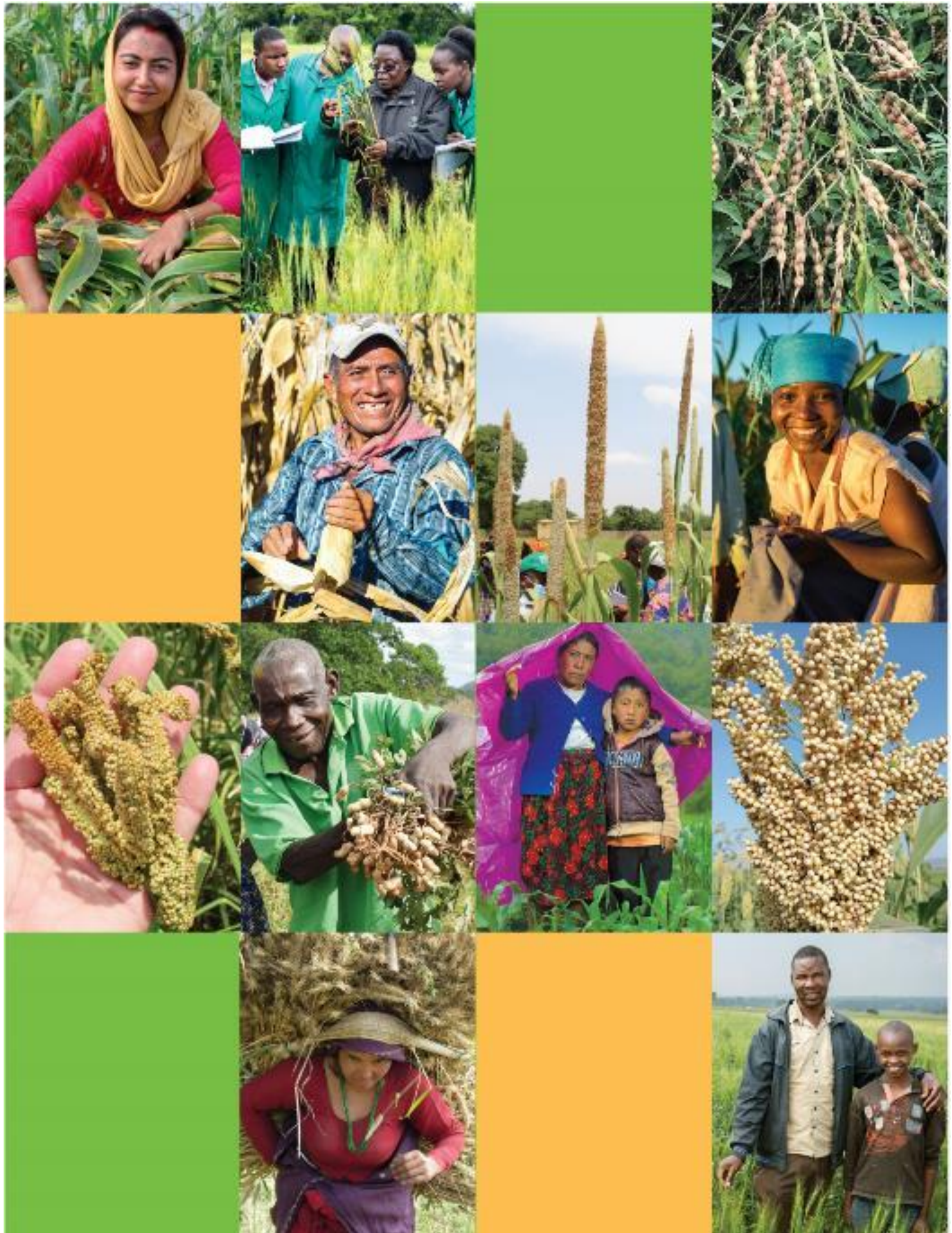
† World Soil Information Service (WOSIS) SOC database
‡ Hengl et al. (2021) *Scientific Report* **11**: 6130. DOI: 10.1038/s41598-021-85639-y
§ Adolwa et al. (2025) *Agricultural Systems 229: 104416*. DOI: 10.1016/j.agsy.2025.104416

4. Conclusions and recommendations

- ❑ Effects of organic inputs on soil health indicators and crop productivity are context-specific; not only **where** but **how** they are applied matters
- ❑ Current tools deliver extension messages without linking the information with soil health indicators

We recommend

- ✓ Use farming systems and soil type (Soil Atlas of Africa) as a template to build site-specific recommendation for organic inputs
- ✓ Design a system based on the infological approach to monitor soil health indicators and hyper-localize the use of organic inputs
- ✓ Enable the application of soil health targeting tools either in the hands of extension workers or farmers themselves



Thank you for your interest!

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