Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Economic Affairs,
Education and Research EAER

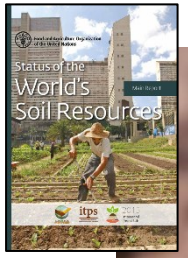
Agroscope

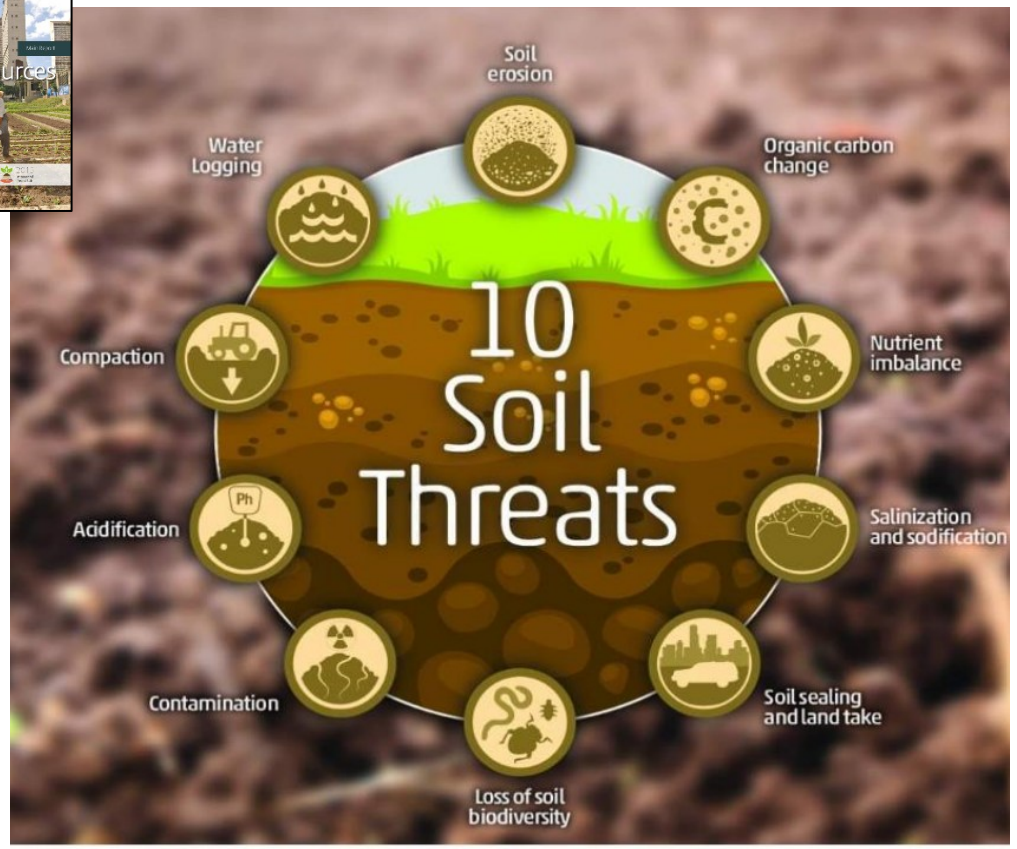
Indicators to guide Sustainable Soil Management

Olivier Heller

EJP SOIL ASD, Aarhus, 6th of October 2025

The State of Soils is bad and often worsening

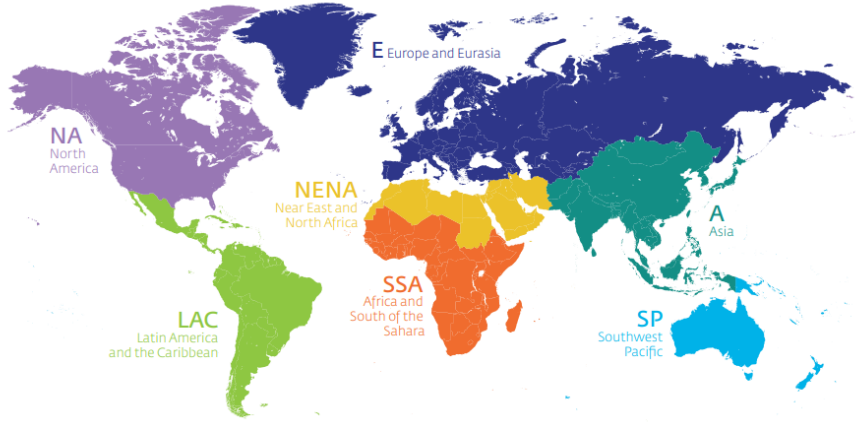




Food and Agriculture Organization of the United Nations

GLOBAL SOIL PARTNERSHIP

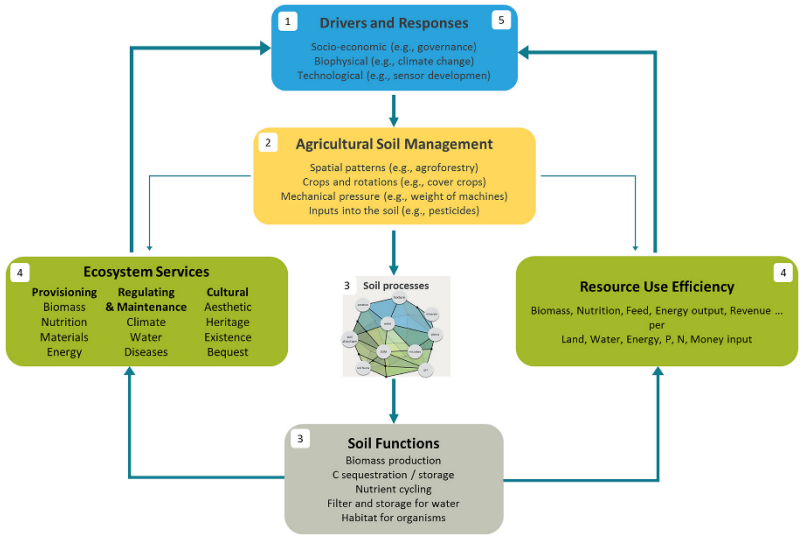
Threat to soil function	Condition and Trend				
	Very poor	Poor	Fair	Good	Very good
Soil erosion	↙ NENA	↙ A ↙ LAC ↙ SSA	↗ E ↗ NA ↗ SP		
Organic carbon change		↘ A ↘ E ↙ LAC ↙ NENA ↙ SSA	↗ NA ↘ SP		
Nutrient imbalance		↙ A ↘ E ↙ LAC ↙ SSA ↙ NA	↙ SP	↘ NENA	

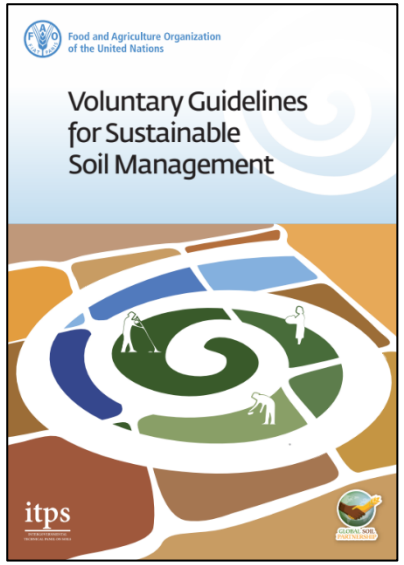


Sources:
FAO and ITPS (2015). Status of the World's Soil Resources – Main Report. LINK
FAO and ITPS (2025). Status of the World's Soil Resources – Main Report. unpublished
Montanarella et al. (2016). World's soils are under threat. *Soil*. doi: 10.5194/soil-2-79-2016
Smith et al. (2024). Status of the World's Soils. An. Rev. of Env. & Res.doi: 10.1146/annurev-environ-030323-075629
Panagos et al. (2024). How the EU Soil Observatory is providing solid science for healthy soils. EJSS. doi: 10.1111/ejss.13507

Soil Management must address Soil Threats

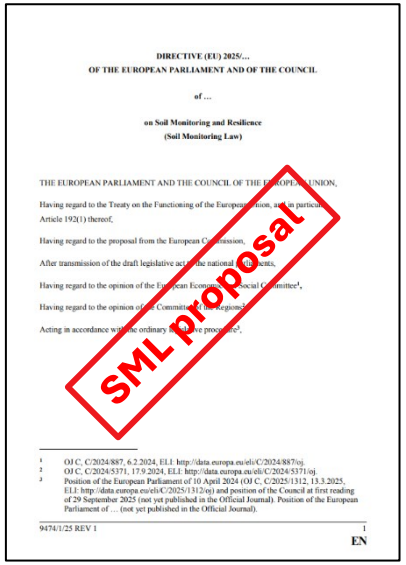
- The Scientific community (e.g., Helming et al. (2018))
- The Voluntary Guidelines for Sustainable Soil Management FAO (2017)
- European Policy:
  - European green deal (Montanarella & Panagos, 2021)
  - Mission soil in Horizon Europe (EC, 2022)
  - The proposed Soil Monitoring Law (EUR-Lex, 2023/0232/COD)





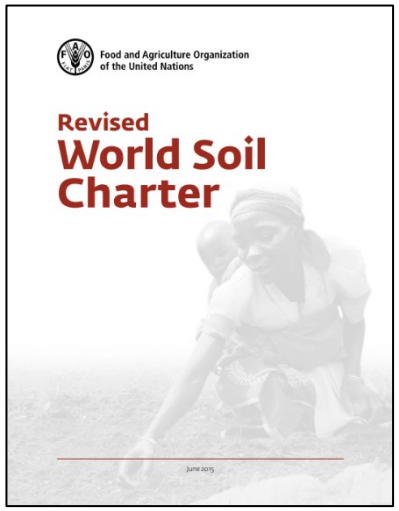
The European Green Deal

EU MISSIONS
SOIL DEAL FOR EUROPE



Sources:
FAO. (2017). Voluntary Guidelines for Sustainable Soil Management. LINK
Helming et al. (2018). Managing soil functions for a sustainable bioeconomy […]. *LDD*. doi: 10.1002/ldr.3066
Montanarella & Panagos. (2021). The relevance of sustainable soil management within the European Green Deal. *Land use policy*. doi: 10.1016/j.landusepol.2020.104950
European Commission. (2022). EU mission, soil deal for Europe. doi: 10.2777/706627
Proposal for the Soil Monitoring Law. Procedure 2023/0232/COD. EUR-Lex. LINK

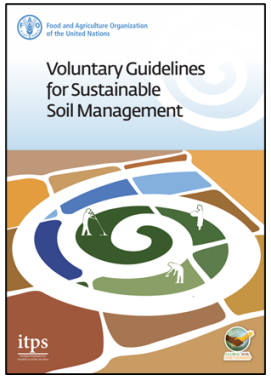
Definition of Sustainable Soil Management

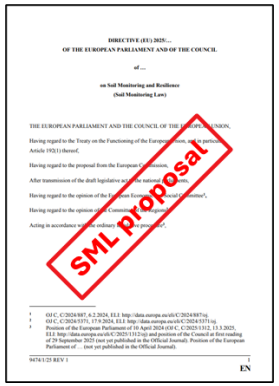


“Soil management is sustainable if the services provided by soil are maintained or enhanced without impairing soil functions or biodiversity. The balance between plant production and regulating water and greenhouse gases is a particular concern.”

- Paraphrased from the Revised World Soil Charter, 3th Principle, adopted by the 39th FAO Conference in June 2015

Eleven characteristics of SSM by FAO (2017)



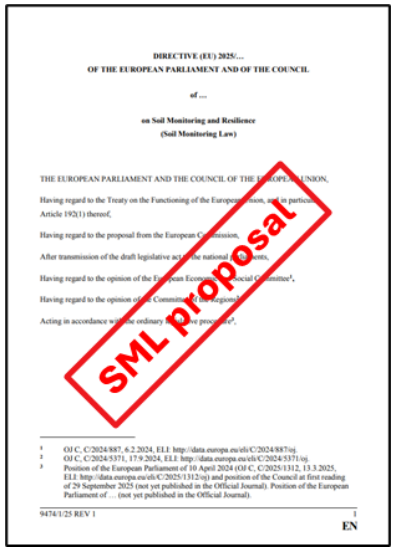


Annex III of the SML proposal by the EC 05/07/2023

European Commission

Sources:
FAO. (2015). Revised World Soil Charter. LINK
FAO. (2017). Voluntary Guidelines for Sustainable Soil Management. LINK
Proposal for the Soil Monitoring Law. Procedure 2023/0232/COD. EUR-Lex. LINK

SML Proposal Article 11: Support for soil health and soil resilience


DIRECTIVE (EU) 2025/...
OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of ...
on Soil Monitoring and Resilience
(Soil Monitoring Law)
THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,
Having regard to the Treaty on the Functioning of the European Union, and in particular Article 192(1) thereof,
Having regard to the proposal from the European Commission,
After transmission of the draft legislative act to the national parliaments,
Having regard to the opinion of the European Economic and Social Committee[1],
Having regard to the opinion of the Committee of the Regions[2],
Acting in accordance with the ordinary legislative procedure[3],
SML proposal
1 OJ C, C/2024/887, 6.2.2024, ELI: http://data.europa.eu/eli/C/2024/887/oj.
2 OJ C, C/2024/5371, 17.9.2024, ELI: http://data.europa.eu/eli/C/2024/5371/oj.
3 Position of the European Parliament of 10 April 2024 (OJ C, C/2025/1312, 13.3.2025, ELI: http://data.europa.eu/eli/C/2025/1312/oj) and position of the Council at first reading of 29 September 2025 (not yet published in the Official Journal). Position of the European Parliament of ... (not yet published in the Official Journal).
9474/1/25 REV 1 1
EN

SML proposal
by the Council and Parliament
29/09/2025

Council of the European Union

European Parliament

- Member States shall encourage and support […] landowners and land managers by:
  - Access to advice, information, training and capacity building
  - Promote awareness and research and innovation
  - **Provide locally-relevant information on practices that increase soil health** [sensu SML]
- Member States shall also:
  - Assess the financial and technical needs to improve soil health
  - Engage with the public concerned […] to determine the support needed
  - Assess the expected soil health effect of other policies

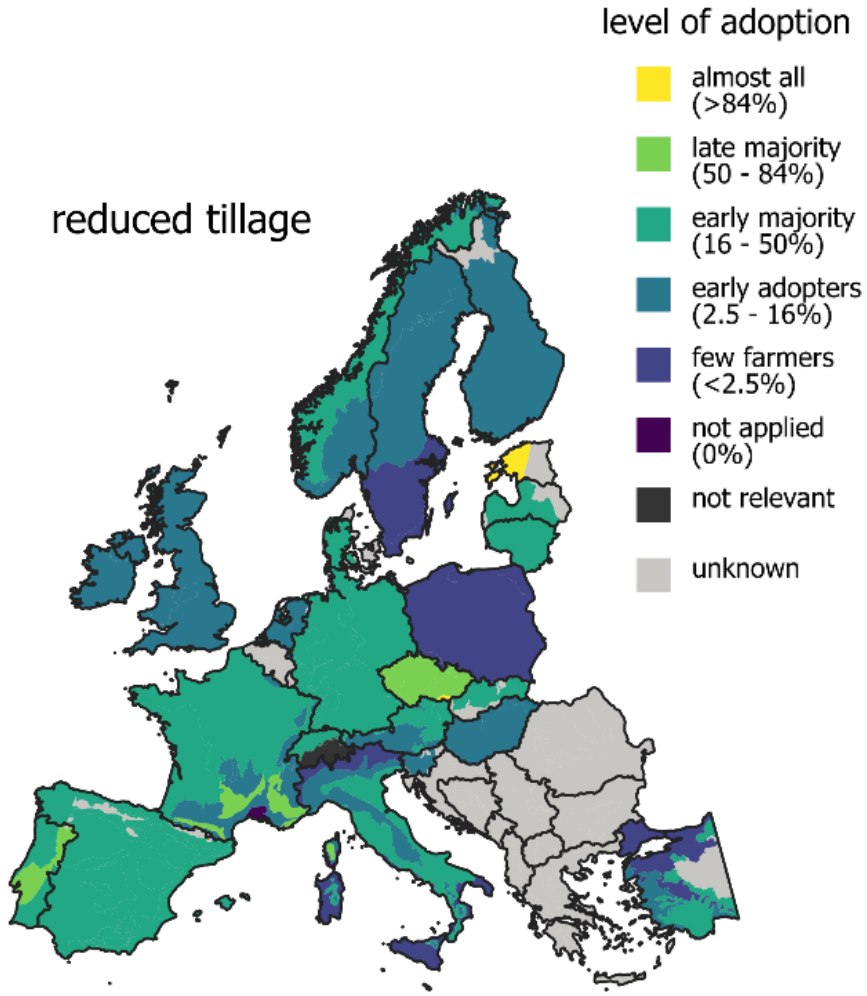
Sources:
Proposal for the Soil Monitoring Law. Procedure 2023/0232/COD. EUR-Lex. LINK

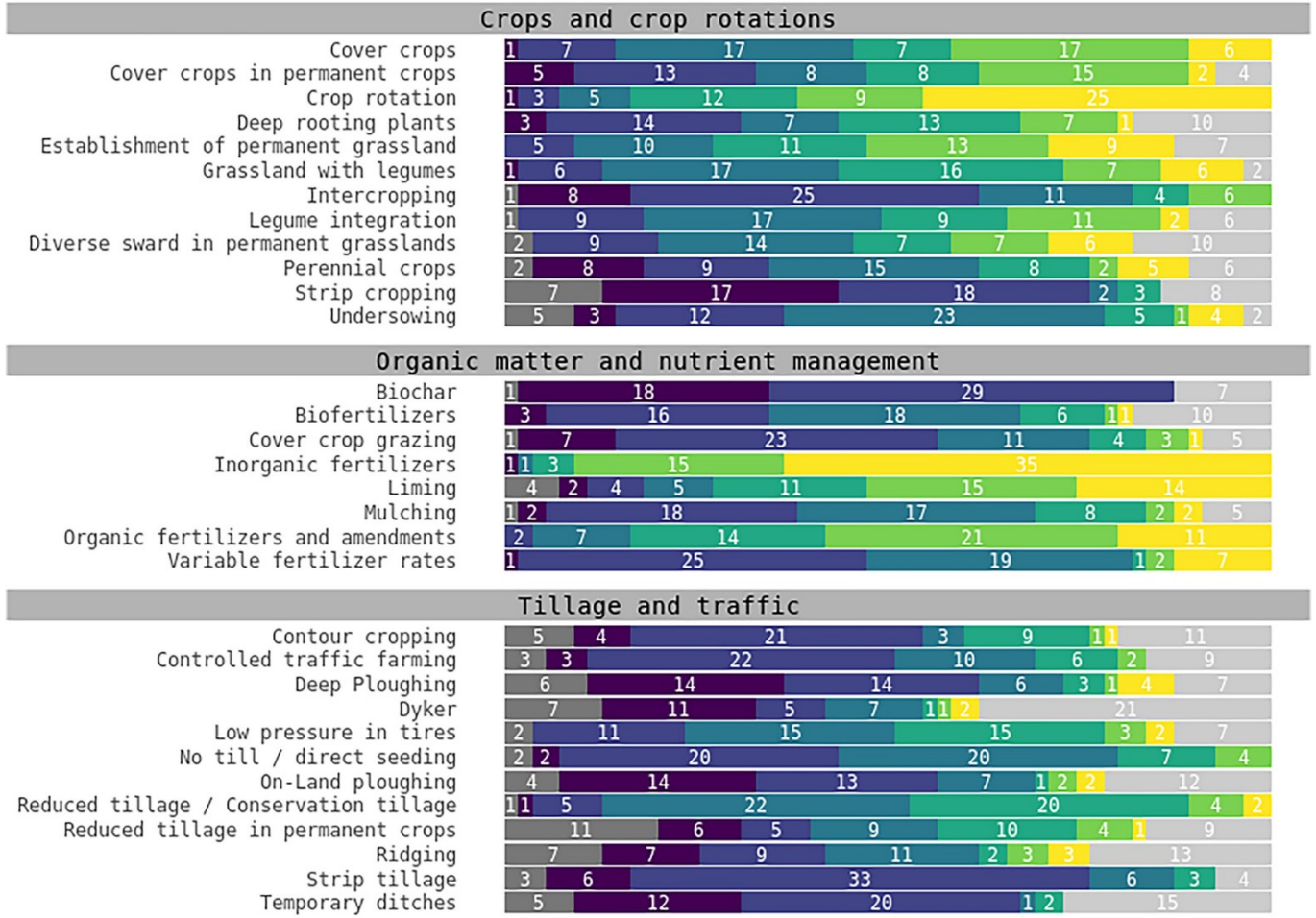
Sustainable soil management systems and practices

- **System Approaches**, based on principles:
  - Conservation Agriculture:
    min. soil disturbance, soil cover, crop rotation FAO
  - Regenerative Agriculture:
    min. soil disturbance, soil cover, crop rotation, living roots, livestock Groundswell
  - Organic Agriculture:
    Health, Ecology, Fairness and Care IFOAM
- **Practices**, that can be applied or not:
  - 2400+ Land management practices in the WOCAT
  - 157 European Farming Practices identified by the JRC Angileri et al. (2024)
  - ~70 Global Soil Management Practices Smith et al. (2024)
  - 53 European Soil Management Practices Heller et al. (2024)

Sources:
Angileri et al. (2024). A classification scheme based on farming practices. doi: 10.2760/33560
Smith et al. (2024). Status of the World's Soils. An. Rev. of Env. & Res. doi: 10.1146/annurev-environ-030323-075629
Heller et al. (2024). Towards enhanced adoption of soil-improving management practices in Europe. EJSS. doi: 10.1111/ejss.13483

Adoption of practices in Europe?

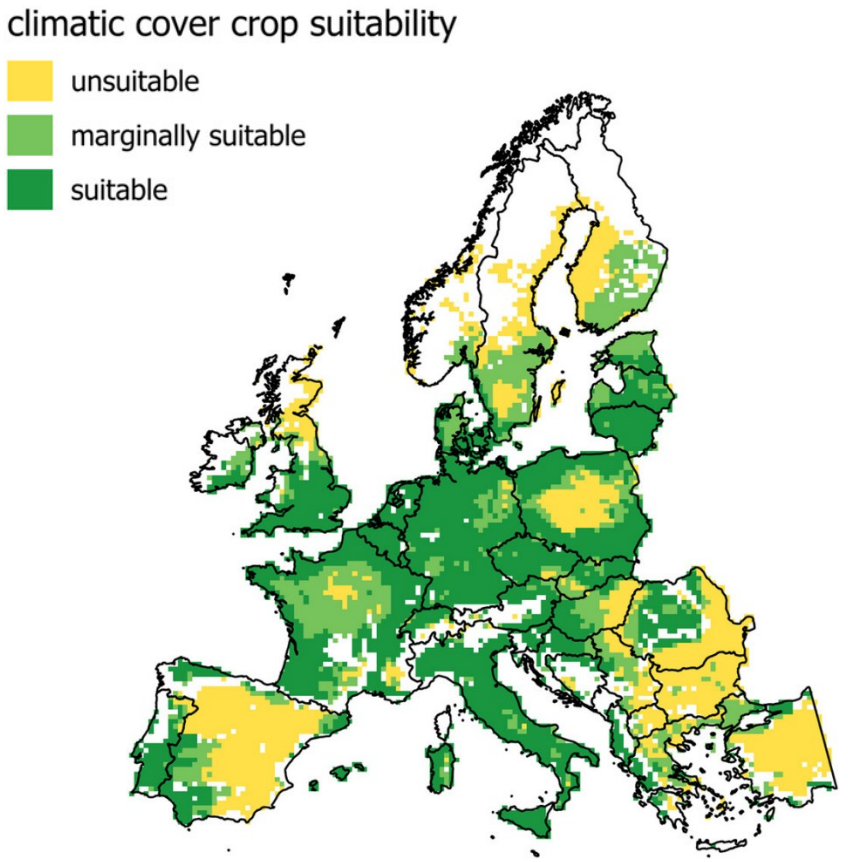




Sources:
Heller et al. (2024). Towards enhanced adoption of soil-improving management practices in Europe. EJSS. doi: 10.1111/ejss.13483

Why is adoption of practices low?

- Bio-physical limits Heller et al. (2024)
- Economic barriers Heller et al. (2024)
  (e.g., costs, investments)
- Technical barriers Heller et al. (2024)
  (e.g., knowledge, machinery)



Heller et al. (2024)

Sources:
Heller et al. (2024). Towards enhanced adoption of soil-improving management practices in Europe. EJSS. doi: 10.1111/ejss.13483
Leonhardt et al. (submitted). A typology of European farmers' viewpoints on soil management and an investigation of their context-dependency
Schreiber et al. (submitted). Who do you strive to be? Exploring ideals of good farming to foster climate-smart soil management
Bütikofer et al. (2024). Zukunftsfähige Bodenbewirtschaftung braucht einen Mix an Unterstützungsmassnahmen. *AFOS*. doi: 10.34776/afs15-279

Why is adoption of practices low?

- Bio-physical limitations Heller et al. (2024)
- Economic barriers Heller et al. (2024)
  (e.g., costs, investments)
- Technical barriers Heller et al. (2024)
  (e.g., knowledge, machinery)
- Social norms Schreiber et al. (submitted)
  (e.g., neat and tidy fields)

© Swiss No-Till

© Syngenta

Sources:
Heller et al. (2024). Towards enhanced adoption of soil-improving management practices in Europe. EJSS. doi: 10.1111/ejss.13483
Leonhardt et al. (submitted). A typology of European farmers' viewpoints on soil management and an investigation of their context-dependency
Schreiber et al. (submitted). Who do you strive to be? Exploring ideals of good farming to foster climate-smart soil management
Bütikofer et al. (2024). Zukunftsfähige Bodenbewirtschaftung braucht einen Mix an Unterstützungsmassnahmen. *AFOS*. doi: 10.34776/afs15-279

Why is adoption of practices low?

- Bio-physical limits Heller et al. (2024)
- Economic barriers Heller et al. (2024)
  (e.g., costs, investments)
- Technical barriers Heller et al. (2024)
  (e.g., knowledge, machinery)
- Social norms Schreiber et al. (submitted)
  (e.g., neat and tidy fields)
- Viewpoints Leonhardt et al. (submitted)
  (e.g., motivations and priorities)

soil farmers

economic farmers

© freihand-zeichner.at

sustainabilty farmers

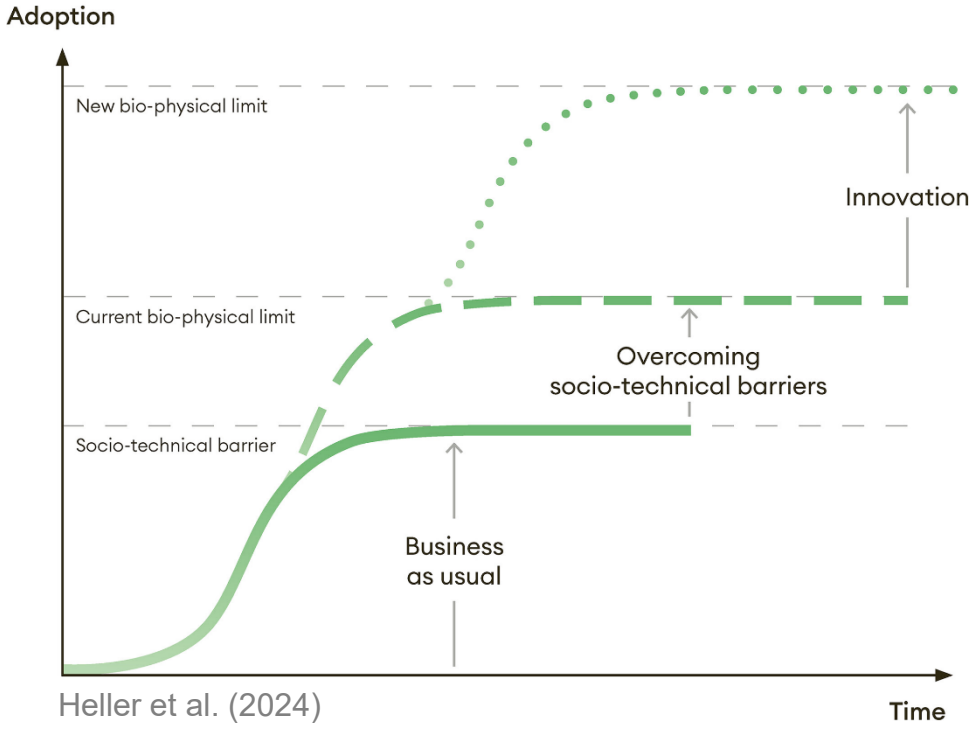
risk-averse farmers

practical farmers

Sources:
Heller et al. (2024). Towards enhanced adoption of soil-improving management practices in Europe. EJSS. doi: 10.1111/ejss.13483
Leonhardt et al. (submitted). A typology of European farmers' viewpoints on soil management and an investigation of their context-dependency
Schreiber et al. (submitted). Who do you strive to be? Exploring ideals of good farming to foster climate-smart soil management
Bütikofer et al. (2024). Zukunftsfähige Bodenbewirtschaftung braucht einen Mix an Unterstützungsmassnahmen. *AFOS*. doi: 10.34776/afs15-279

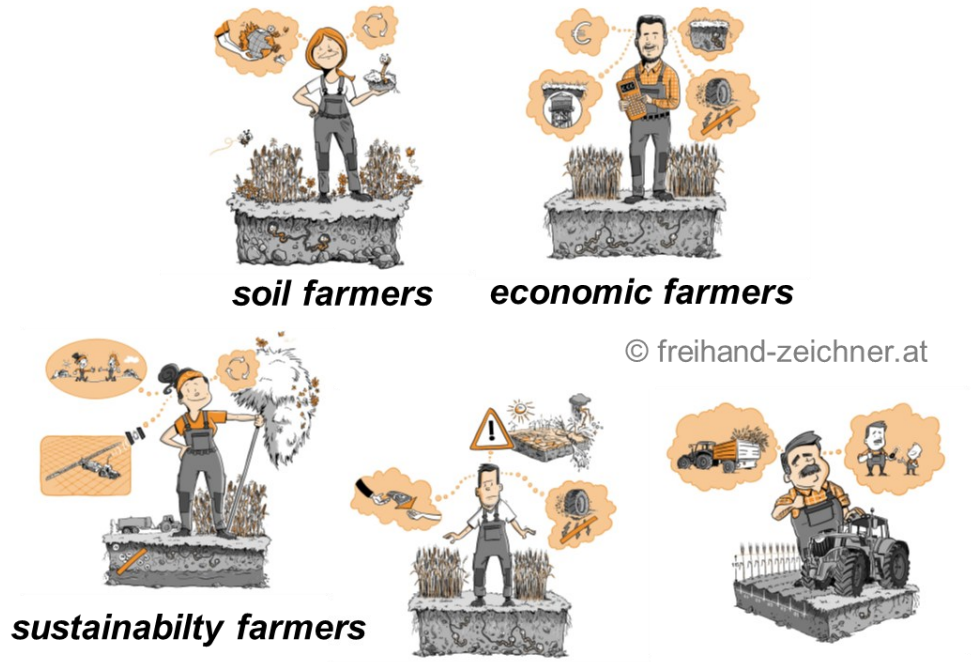
How to increase the adoption?

- Economic insentives
- Information and advice



Heller et al. (2024)

- Innovation
- Account for Norms and Viewpoints



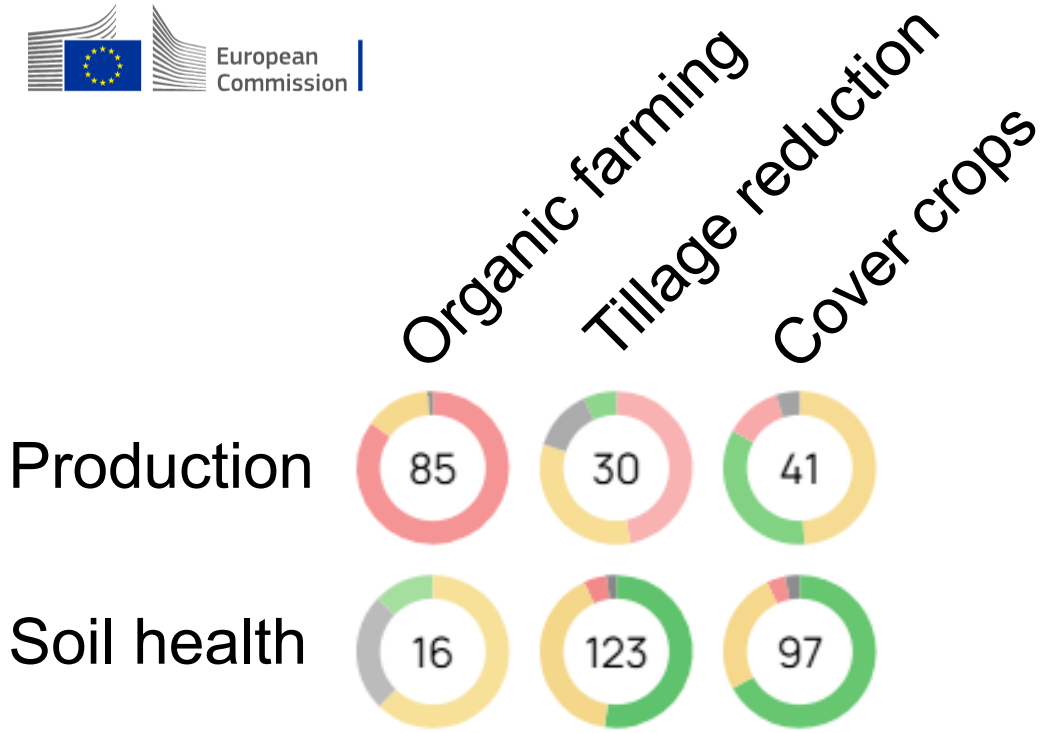
Leonhardt et al. (submitted)

Sources:
Heller et al. (2024). Towards enhanced adoption of soil-improving management practices in Europe. EJSS. doi: 10.1111/ejss.13483
Leonhardt et al. (submitted). A typology of European farmers' viewpoints on soil management and an investigation of their context-dependency
Schreiber et al. (submitted). Who do you strive to be? Exploring ideals of good farming to foster climate-smart soil management
Bütikofer et al. (2024). Zukunftsfähige Bodenbewirtschaftung braucht einen Mix an Unterstützungsmassnahmen. *AFOS*. doi: 10.34776/afs15-279

Outcome depends on pedo-climatic context

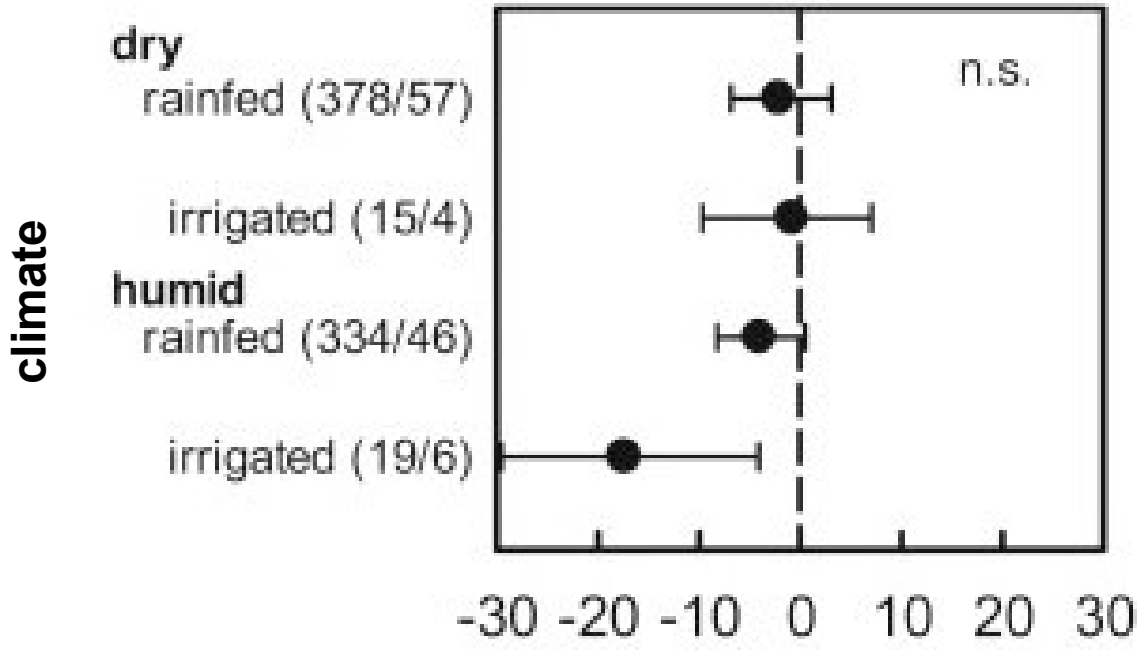
JRC - Farming practices Evidence Library

European Commission



Schievano et al. (2025)

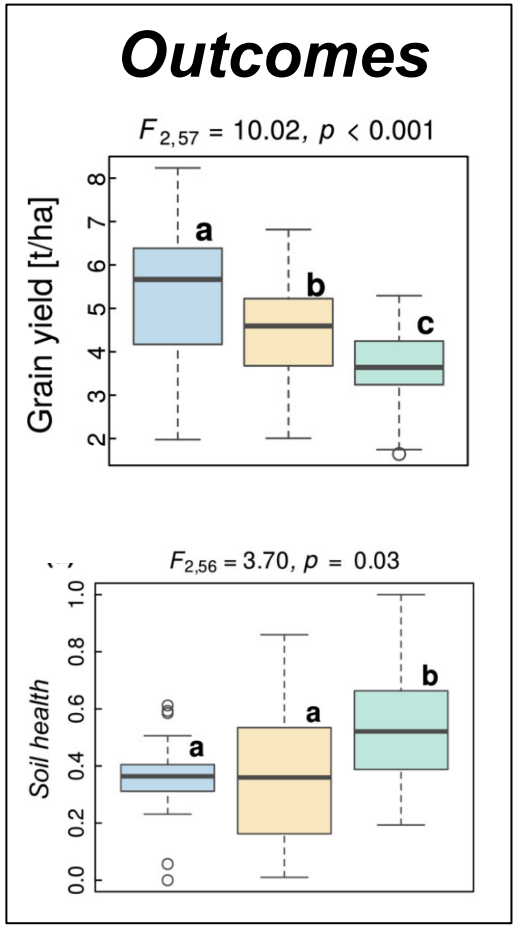
effect of no-till on cereal yield



Pittelkow et al. (2015)

Sources:
Pittelkow et al. (2015). When does no-till yield more? A global meta-analysis. *Field Crops Research*. doi: 10.1016/j.fcr.2015.07.020
Schievano et al. (2025). The JRC farming practices evidence library. doi: 10.2760/9473570

Outcome depends on pedo-climatic context and management intensity



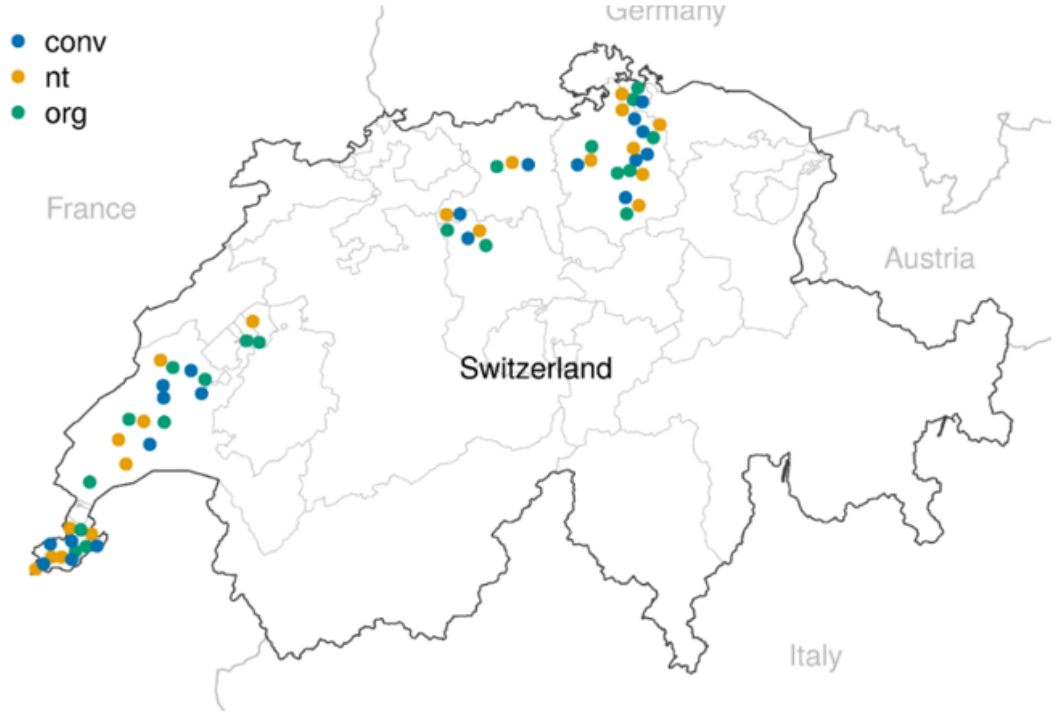


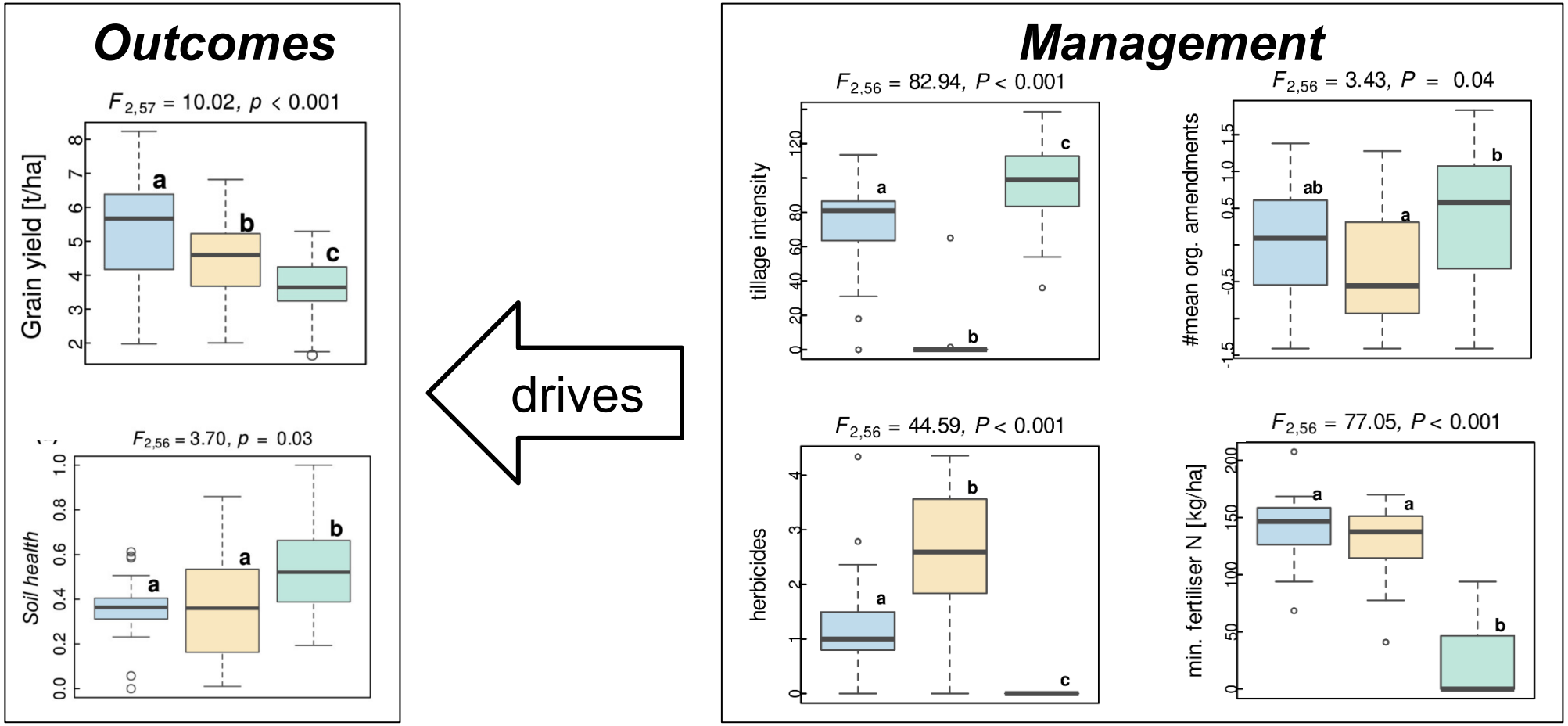
Figure S1 | On-farm network across Switzerland, consisting of conventional, no-till and organic farms.

Conventional No-till Organic

Büchi et al. (2019), Walder et al. (2023)

Sources:
Büchi et al. (2019). Potential of indicators to unveil the hidden side of cropping system classification […]. Eur. J. of Agronomy. doi: 10.1016/j.eja.2019.125920
Walder et al. (2023). Synergism between production and soil health […]. Journal of Applied Ecology. doi: 10.1111/1365-2664.14484

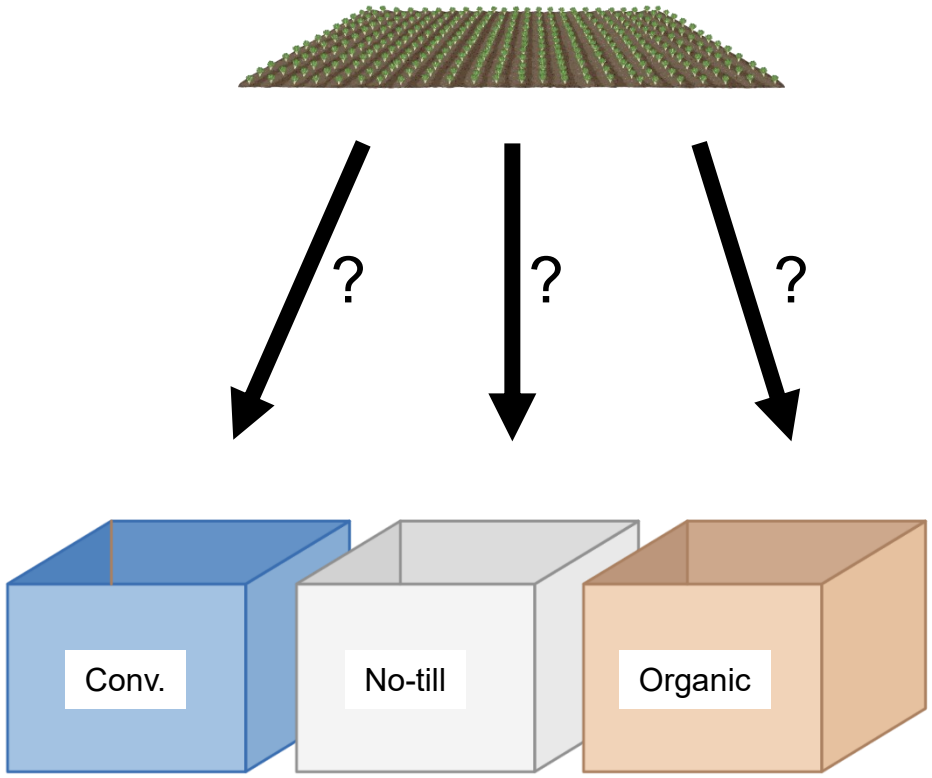
Outcome depends on pedo-climatic context and management intensity

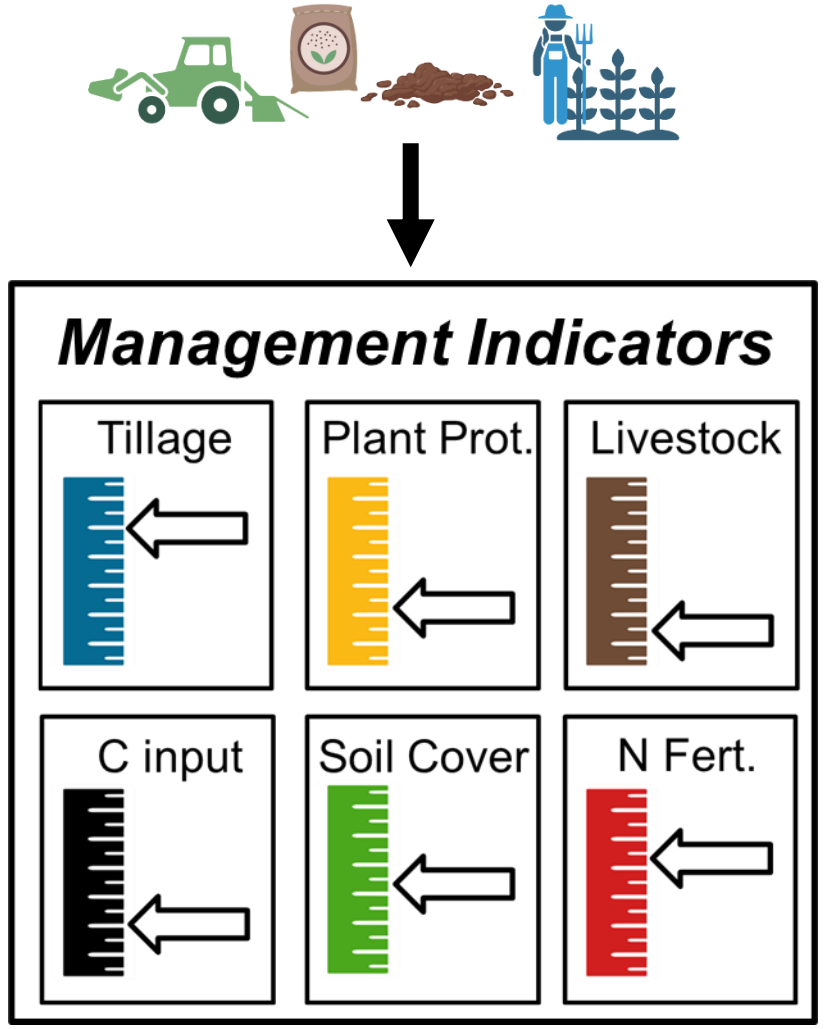


Büchi et al. (2019), Walder et al. (2023)

Sources:
Büchi et al. (2019). Potential of indicators to unveil the hidden side of cropping system classification […]. Eur. J. of Agronomy. doi: 10.1016/j.eja.2019.125920
Walder et al. (2023). Synergism between production and soil health […]. Journal of Applied Ecology. doi: 10.1111/1365-2664.14484

From boxes to management indicators

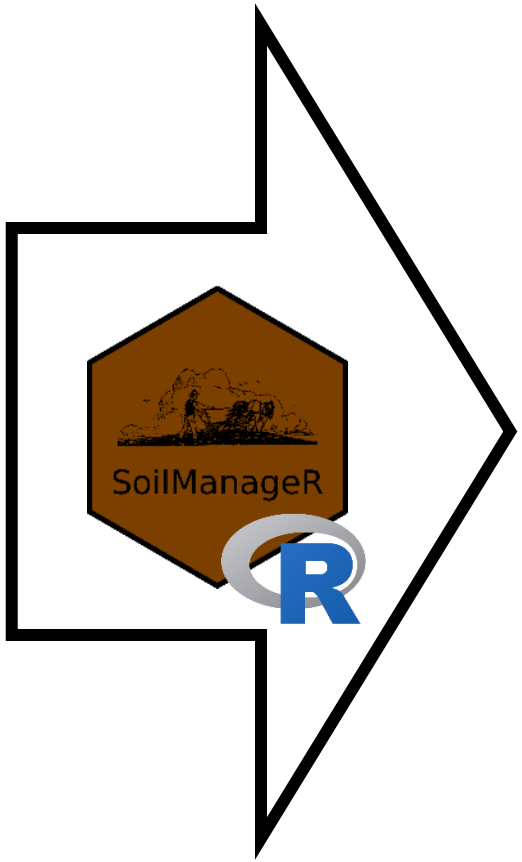




SoilManageR to calculate indicators

Management Information (categorical and numerical)

date	category	operation	device	value	unit
2009-08-24	sowing	sowing_cover_crop	direct_drill	50.00	kg/ha
2009-10-08	tillage	stubble_cultivation	mulching	NA	NA
2009-10-08	tillage	primary_tillage	plough	20.00	cm
2009-10-20	tillage	seedbed_preparation	rotary_harrow	10.00	cm
2009-10-21	sowing	sowing_main_crop	direct_drill	190.00	kg/ha
2009-10-21	crop_protection	fungicide	seed_coating	0.38	l/ha
2010-03-19	fertilizer_application	mineral_fertilization	solid_broadcast	50.00	kg N/ha
2010-03-25	crop_protection	weed_herbicide	sprayer_broadcast	3.00	l/ha
2010-04-09	fertilizer_application	mineral_fertilization	solid_broadcast	30.00	kg N/ha
2010-05-17	fertilizer_application	mineral_fertilization	solid_broadcast	30.00	kg N/ha
2010-08-04	harvest	harvest_main_crop	combine_harvester	NA	NA
2010-08-09	harvest	straw_removal	square_baler	NA	NA
2010-08-10	tillage	stubble_cultivation	fine_cultivator	10.00	cm
2010-08-13	sowing	sowing_cover_crop	direct_drill	50.00	kg/ha
2011-04-15	tillage	stubble_cultivation	mulching	NA	NA
2011-04-18	tillage	primary_tillage	plough	20.00	cm
2011-04-28	tillage	seedbed_preparation	rotary_harrow	10.00	cm
2011-04-29	sowing	sowing_main_crop	direct_single_grain	95000.00	plants/ha
2011-04-29	crop_protection	insecticide	seed_coating	142.50	g/ha
2011-05-10	fertilizer_application	mineral_fertilization	solid_broadcast	30.00	kg N/ha
2011-05-10	fertilizer_application	mineral_fertilization	solid_broadcast	47.00	kg P2O5/ha
2011-05-31	crop_protection	weed_herbicide	sprayer_broadcast	1.00	l/ha



Soil Management Indicators (numerical)

- Carbon Input
- Soil Cover
- Tillage
- Livestock
- Nitrogen Input
- Plant Diversity
- Plant protection
- …

Use cases:

- **Compare management of different fields and experiments**
- **Assess the impact of management on response variables**
- **Assess temporal changes in management**

Available on CRAN

Heller et al. (2025)

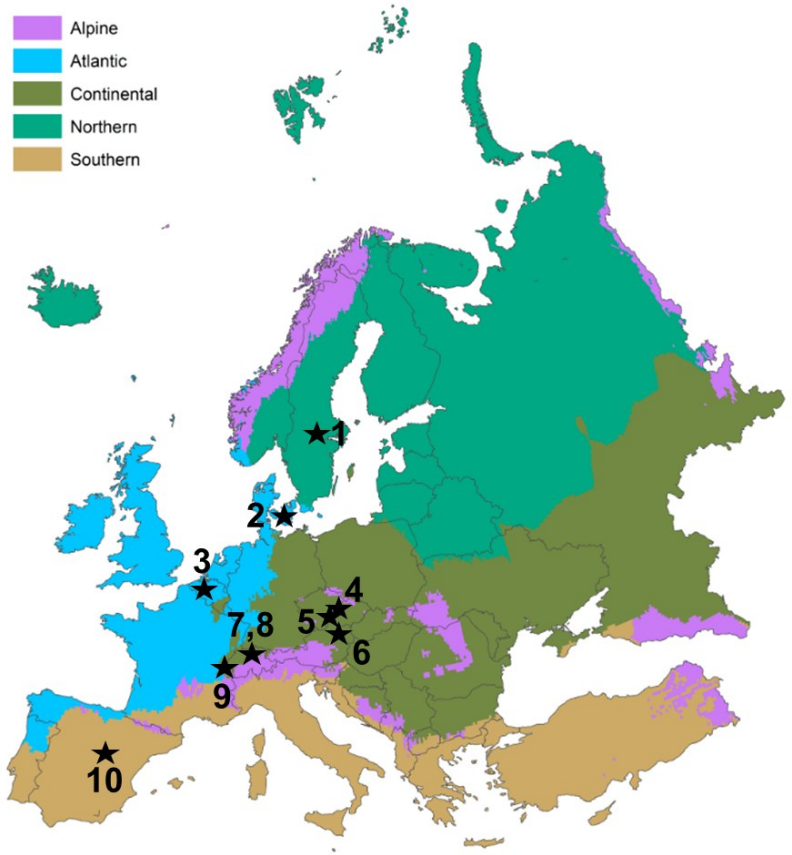
Sources:
Heller et al. (2025). SoilManageR—An R Package for Deriving Soil Management Indicators. EJSS. doi: 10.1111/ejss.70102

Example 1:

Soil Management for Extreme Weather Resilience: Evidence from ten European LTEs

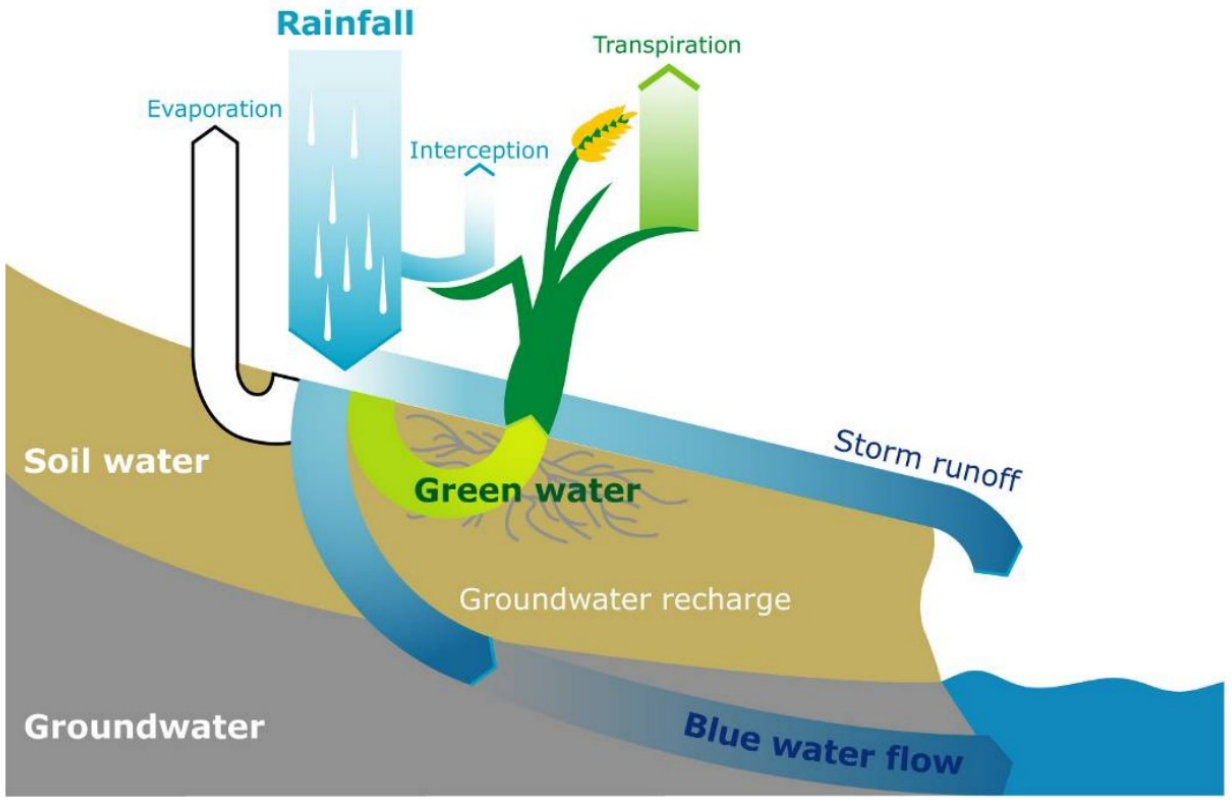
Agroscope

Soil Management for Extreme Weather Resilience



Map from Metzger (2018), doi.org/10.7488/ds/2416

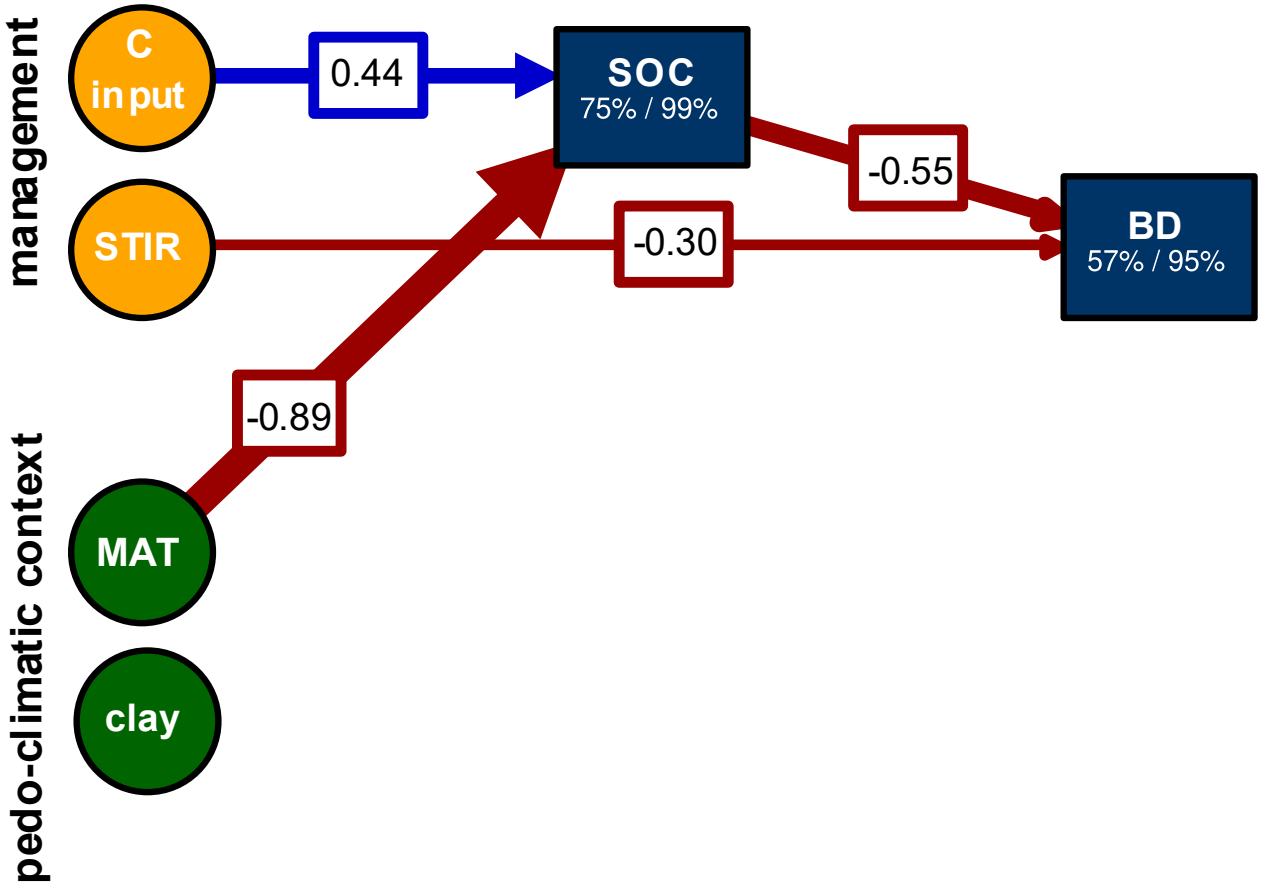
Heller et al. (in prep)



Geerisman et al. (2009)

Sources:
Heller et al. (in prep). Pedo-climatic conditions, tillage intensity and carbon input drive arable soils' physical properties
Geertsma, R., L.I. Wilschut and J.H. Kauffman. (2009). Baseline Review of the Upper Tana, Kenya. *Green Water Credits Report 8*. ISRIC.

Soil Management for Extreme Weather Resilience

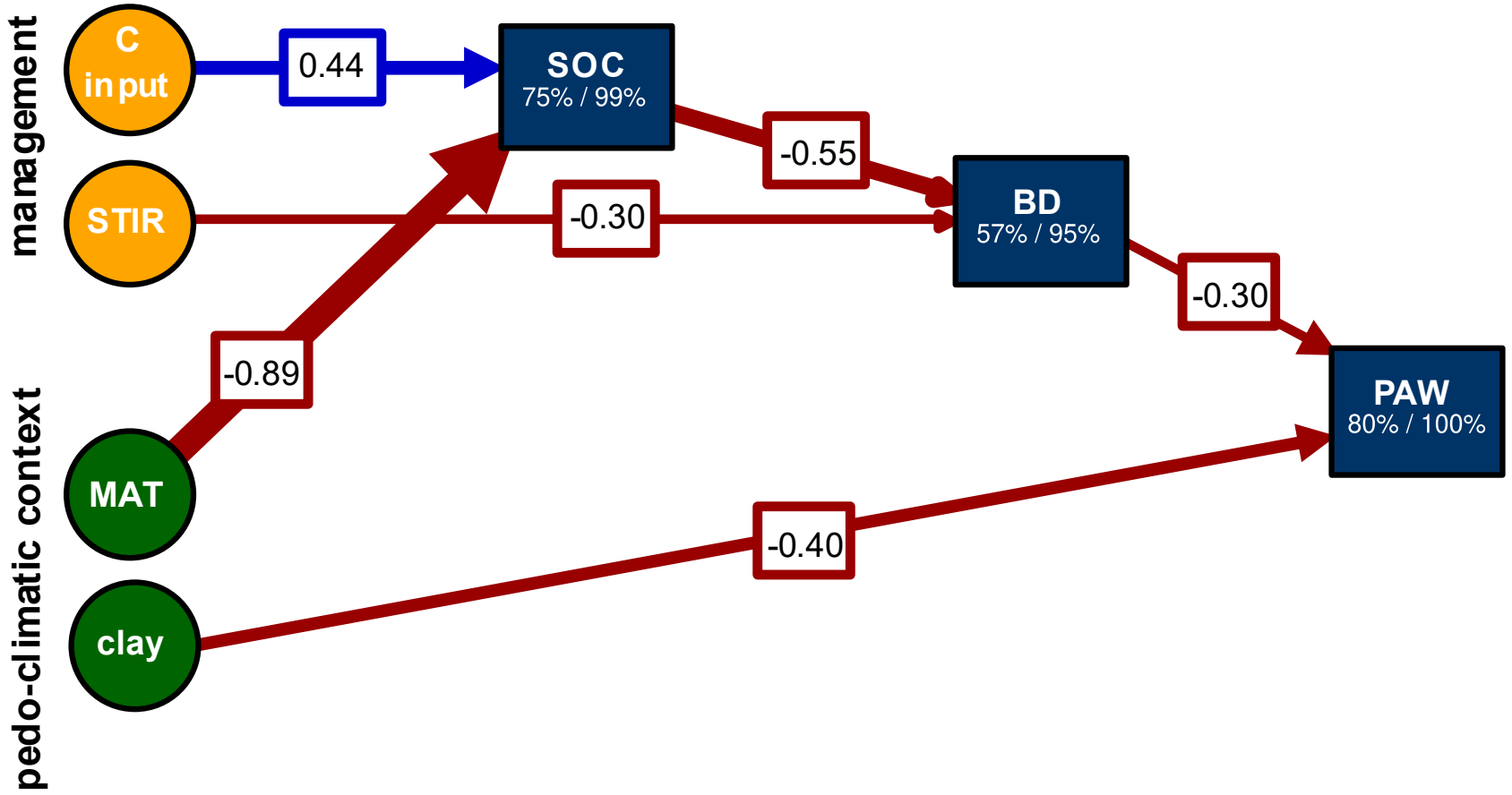


Only effects with |relative effect size| > 0.25 and a p-value < 0.05 are shown.

Heller et al. (in prep)

Agroscope

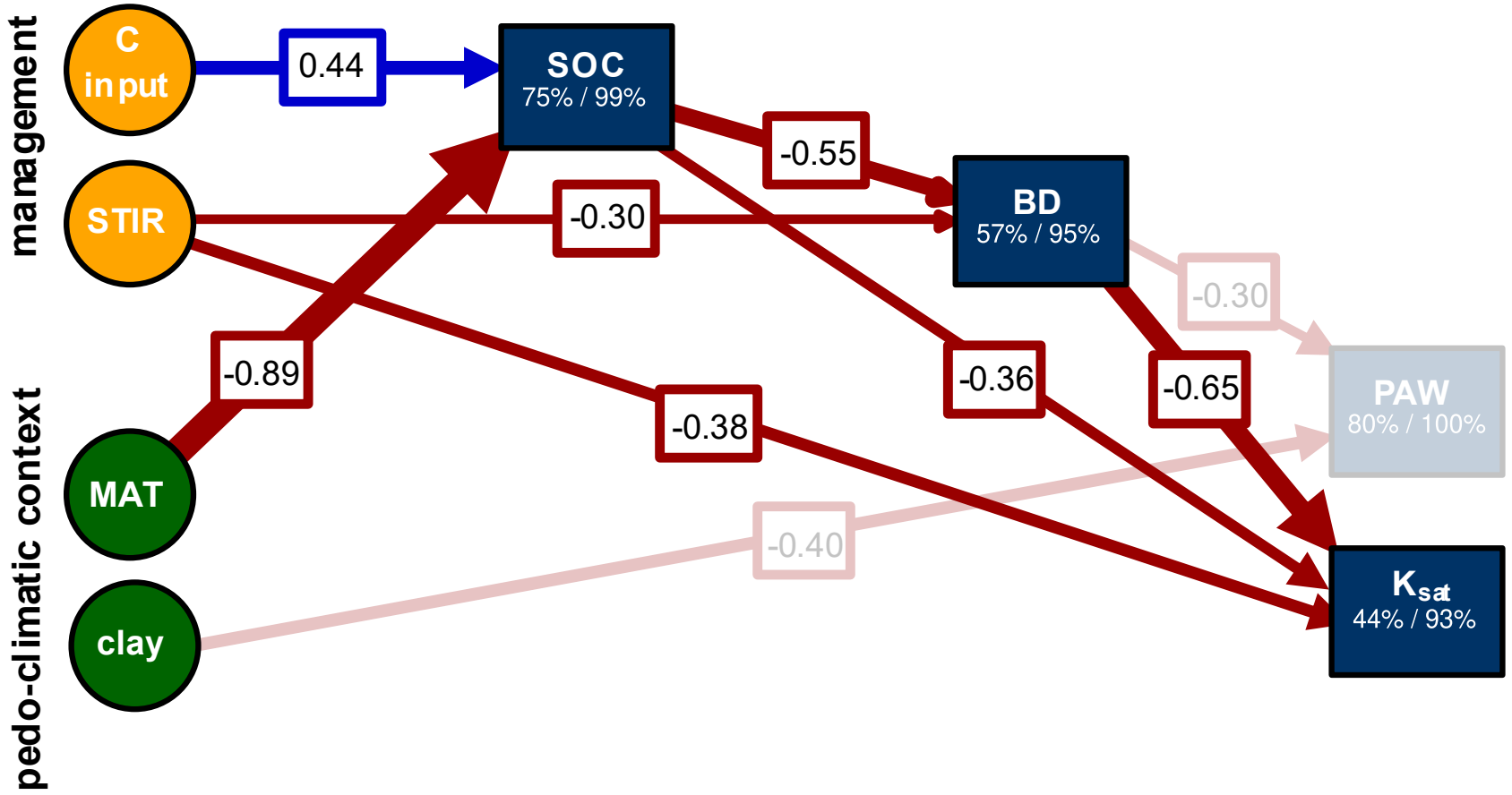
Soil Management for Extreme Weather Resilience



Only effects with |relative effect size| > 0.25 and a p-value < 0.05 are shown.

Heller et al. (in prep)

Soil Management for Extreme Weather Resilience

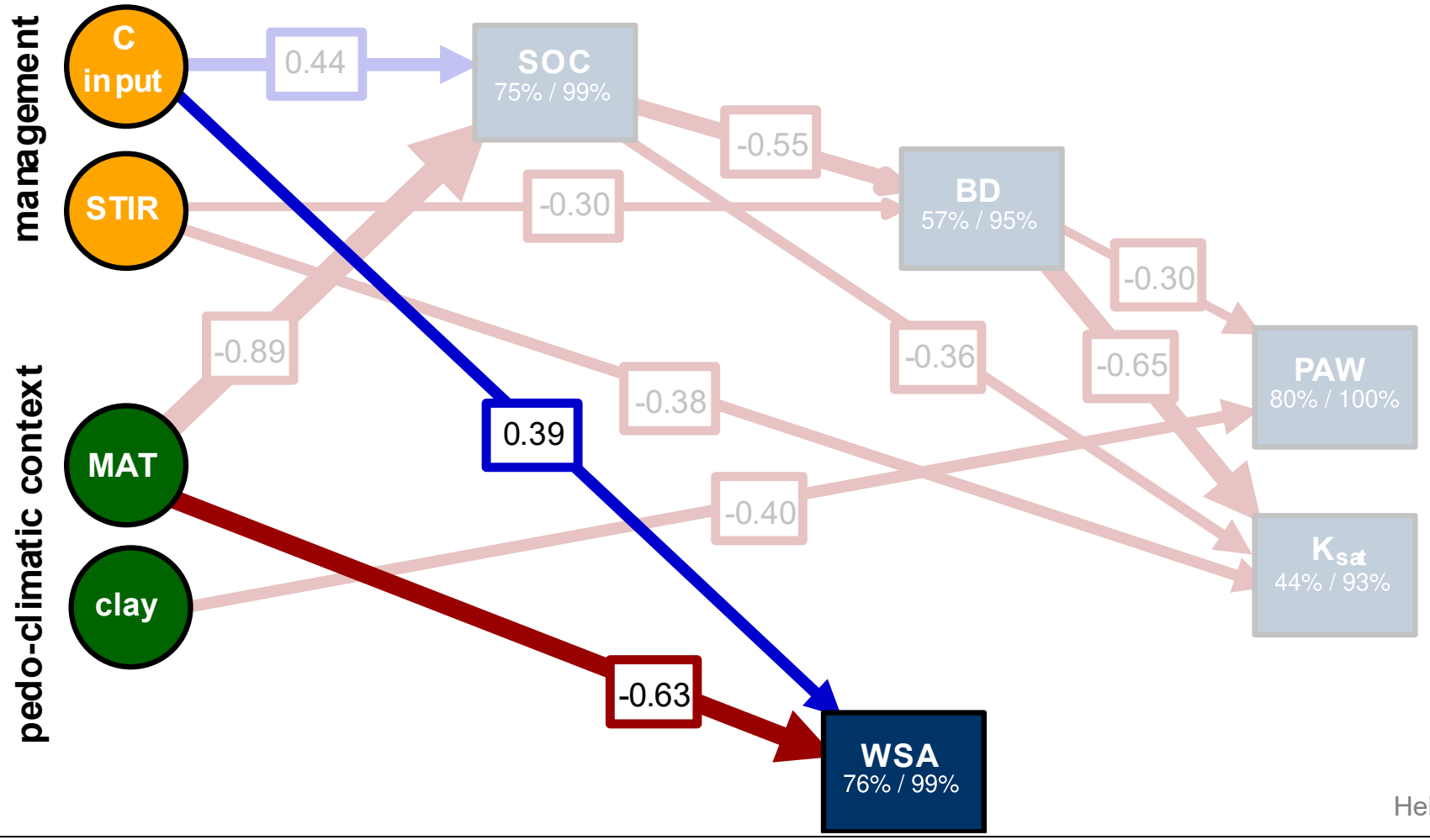


Only effects with |relative effect size| > 0.25 and a p-value < 0.05 are shown.

Heller et al. (in prep)

Sources:
Heller et al. (in prep). Pedo-climatic conditions, tillage intensity and carbon input drive arable soils' physical properties

Soil Management for Extreme Weather Resilience



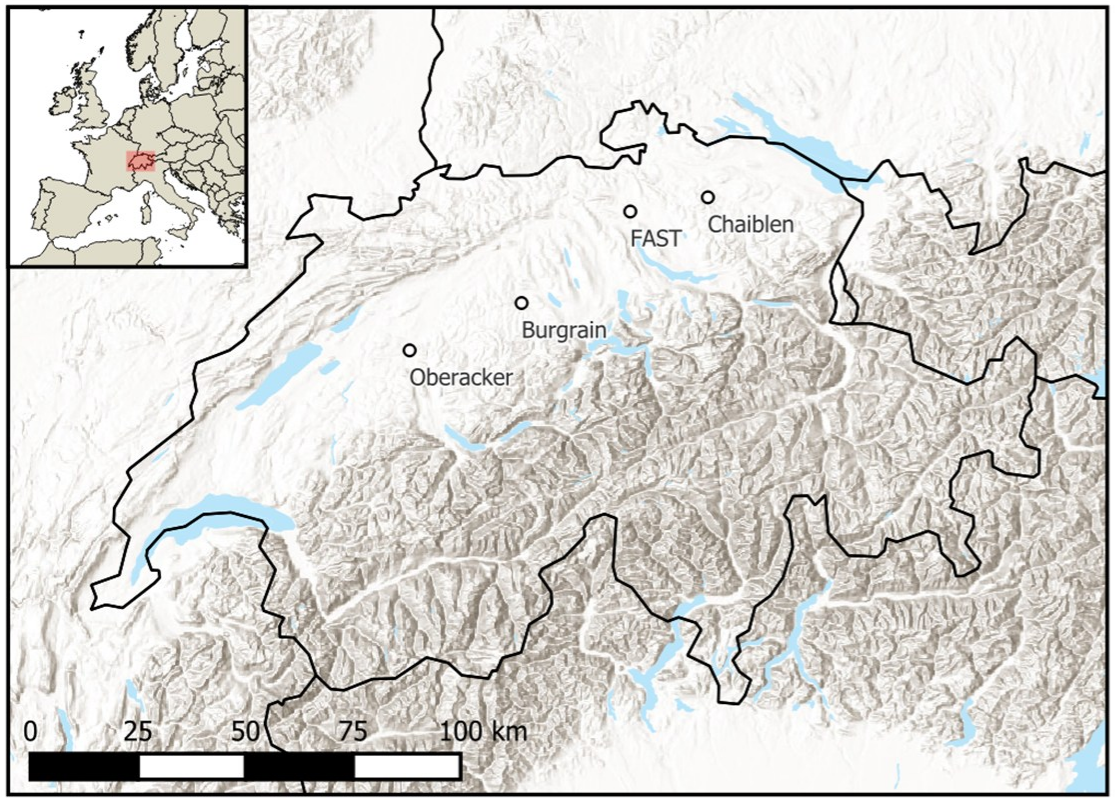
Heller et al. (in prep)

Sources:
Heller et al. (in prep). Pedo-climatic conditions, tillage intensity and carbon input drive arable soils' physical properties

Example 2:

Soil Management effects on Crop Production: Insights from four Swiss LTEs

Soil Management effects on Crop Production



Trial	Soil	Management
Oberacker 1994 - present	sandy loam, eutric Cambisol	4: ploughed / no-till x GRUD / Kinsey fertilization
Burgrain 1991 - 2008	sandy clay loam, gleyic Cambisol	3: conventional / integrated / organic
FAST 2009 - present	loam, calcaric Cambisol	16: conv./no-till/ organic/org. red. till x cov. crops x 2 N-levels
Chaiblen 1989 - 2000	clay, gleyic Cambisol	6: 3 crop rotations x intensive / extensive

Figure 1: Location, soil, and management of the investigated LTEs

Kessler Seiz et al. (2025)

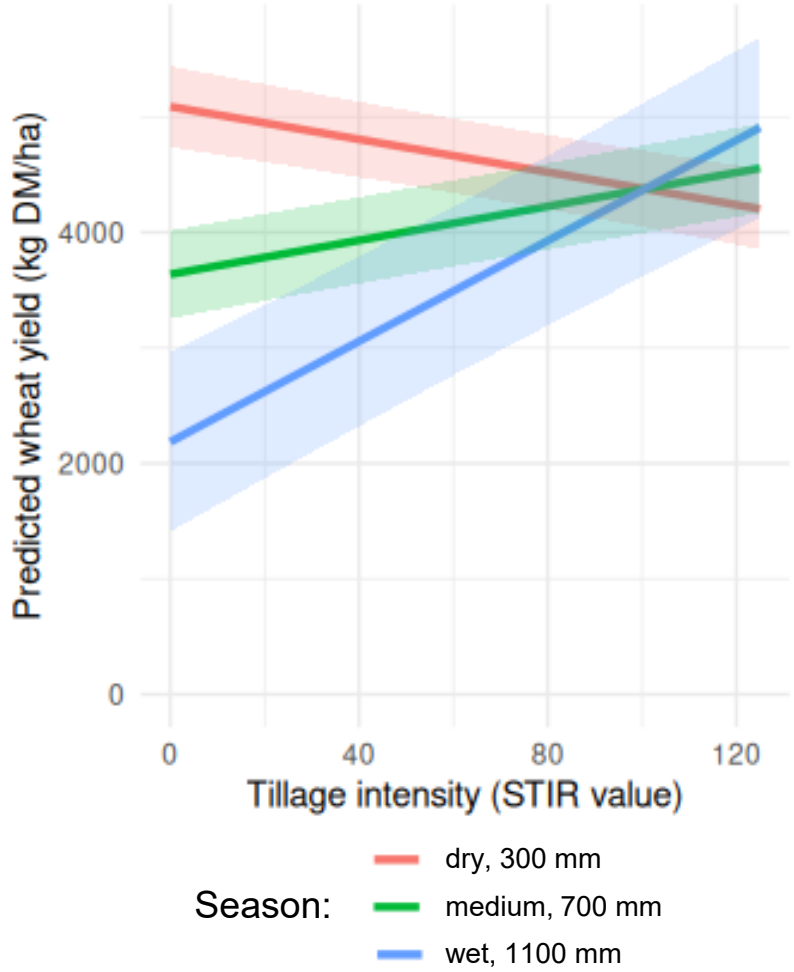
Sources:
Kessler Seiz et al. (2025). Soil Management effects on Crop Production and Soil Health: Insights from four Swiss Long-term Field Trials. *EUROSOIL*. LINK

Soil Management effects on Crop Production

Table 1: Estimates of the fixed effects of the mixed model for wheat yield in kgDM ha^{-1}. Significance codes represent *p*-values. *: *p*-value < 5%, **: *p*-value < 1%, ***: *p*-value < 0.1%

Term	Estimate Std. Error	Significance
Intercept	7783 ± 2941	*
Mineral N input (kg ha^{-1})	21.2 ± 3	***
- interaction with spring precipitation	-0.045 ± 0.011	***
Tillage intensity (STIR)	-17.3 ± 4.5	***
- interaction with summer precipitation	0.03 ± 0.01	*
- interaction with spring precipitation	0.042 ± 0.01	***
Plant protection intensity (applications)	1296 ± 307	***
- interaction with spring precipitation	1.21 ± 0.37	**
- interaction with summer temperature	-79.4 ± 16.2	***
Summer precipiation (mm)	-3.9 ± 1.9	*
Summer temperature (°C)	-126 ± 140	
Spring precipiation (mm)	-2 ± 1.8	

$n = 613$, $R_2^M = 43\%$, $R_2^C = 83\%$



Kessler Seiz et al. (2025)

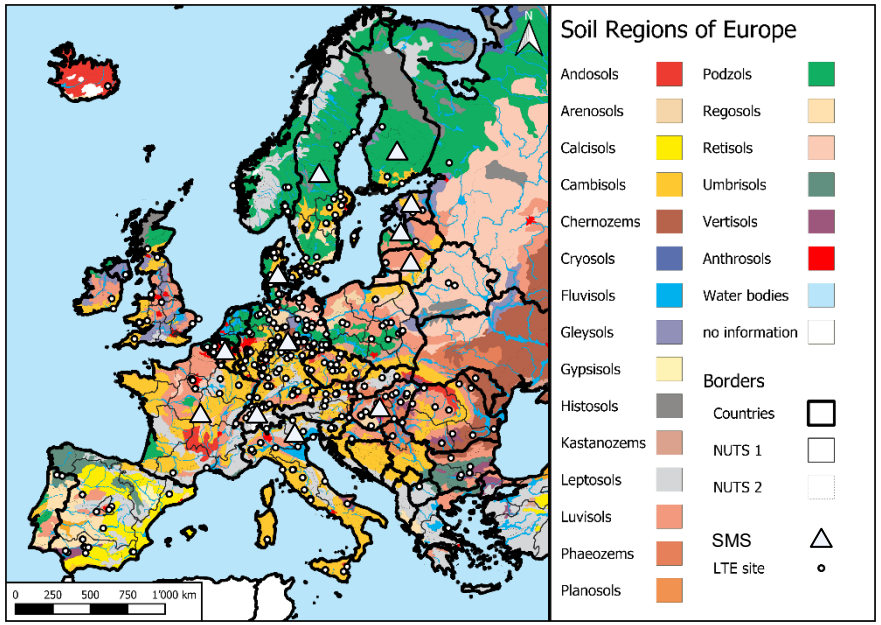
Sources:
Kessler Seiz et al. (2025). Soil Management effects on Crop Production and Soil Health: Insights from four Swiss Long-term Field Trials. *EUROSOIL*. LINK

Conclusions and Outlook

- Many practices for sustainable soil managment exist
- Adoption can be improved by adressing bio-physical limits and socio-technical barriers
- Quantitative Soil Management Indicators…
  - … can compare management effects across sites (i.e., physical soil properties and winter wheat yield)
  - … facilitate interpretation and communication

Conclusions and **Outlook**

- Harmonise ***more*** existing data (e.g. from LTEs, Monitoring Systems, living labs)
- Establish clear links to soil health indicators and functions
- Establish context-specific intensity thresholds for sustainable soil management



Blanchy et al. (2024), Mason et al. (2025), EUSR5000

Existing data:

- ➢240+ LTEs in Europe Blanchy et al. (2024)
- ➢17+ Soil Monitoring Systems Mason et al. (2025)
- ➢Living labs, from Mission Soil etc.
- ➢…

Sources:
Blanchy et al. (2024). An open-source metadataset of running European mid- and long-term agricultural field experiments. *SUM*. doi: 10.1111/sum.12978
EUSR5000. Soil Regions of the EU and adjacent countries 1:5'000'000. LINK
Mason et al. (2025). Monitoring Systems of Agricultural Soils Across Europe […]. *EJSS*. doi: 10.1111/ejss.70163

Agroscope
















Thank you for your attention

Olivier Heller
olivier.heller@agroscope.admin.ch

Agroscope good food, healthy environment
www.agroscope.admin.ch












Agroscope