

Novel soil quality indicators for the evaluation of agricultural management practices: a biological perspective

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Supplementary materials

Table S1 Characteristics of the ten European long-term field experiments used in the current study^[1]

LTE	Location	Coordinates	Year	Climate	Soil type (WRB)	Land use and treatment factor	Sampling depth(s)/cm	Experimental design and No. of reps.	Reference
Frick experiment CH1	Switzerland	47° 30' 40" N 8° 01' 26" E	2002	MAT: 10.3°C MAP: 1130 mm (Dfb)	Vertic Cambisol	Arable Tillage (Conventional or Reduced)	0–10 10–20	Split plot design with 4 reps.	[2]
Aesch experiment CH2	Switzerland	47° 28' 54" N 7° 34' 46" E	2010	MAT: 10.6°C MAP: 992 mm (Dfb)	Haplic Luvisol	Arable Tillage (Conventional or Reduced)	0–10 0–20	Split plot design with 4 reps.	[3]
DOK experiment CH3	Switzerland	47° 30' 08" N 7° 32' 25" E	1978	MAT: 11.2°C MAP: 700 mm (Dfb)	Haplic Luvisol with Löss	Arable Organic matter input (Mineral or Biodynamic system)	0–20	Randomized block design with 4 reps.	[4,5]
BASIS experiment NL1	The Netherlands	52° 27' N 05° 31' E	2008	MAT: 9.5 C MAP: 750 mm (Cfb)	Haplic Fluvisol	Arable Tillage (Conventional or Minimum) and Organic	0–15 15–30	Split plot block design with 3 reps.	[6]

						matter input (None or Cut-and-carry)			
Vredepeel experiment NL2	The Netherlands	51° 32' 27" N 5° 52' 05" E	2001	MAT: 10.5 MAP: 775 mm (Cfb)	Gleyic Podzol	Arable Tillage (Conventional or Non-Inversion) and Organic matter input (Integrated or Conventional)	0–10 10–20	Split plot block design with 3 reps.	None
Vitichar experiment PT1	Portugal	40° 26' 26" N 8° 26' 23" W	2013	MAT: 15°C MAP: 1000-1200 mm (Csb)	Cambisol	Permanent crop (grapevine) Organic matter input (Control, Biochar-compost or 40 t·ha ⁻¹ Biochar)	0–20	Randomized block design with 3 reps.	None
PAGO experiment ES4	Spain	38° 49' 20" N 0° 48' 32" W	2005	MAT: 16.3° MAP: 420 mm (Bsk)	Cambisol	Permanent crop (grapevine) Organic matter input (Organic + leguminous cover crops and no tillage or Conventional plus tillage)	0–10 10–20	Randomized block design with 3 reps.	[7]
Tillorg experiment SI1	Slovenia	46° 02' 56" N 14° 28' 16" E	1999	MAT: 11.3°C MAP: 1380 mm (Dfc)	Eutric Gleysol	Arable Tillage (Conventional or Non-Inversion) and Organic matter input (NPK or Bio-waste)	0–10 10–20	Split plot design with 3 reps.	[8]
Keszthely fertilization experiment HU1	Hungary	46° 43' 60" N 17° 13' 49" E	1984	MAT: 10.5°C MAP: 683 mm (Dfb)	Eutric Cambisol	Arable Organic matter input (Farmyard or Straw-green or Inorganic fertilizer 210 kg·ha ⁻¹ N)	0–20	Split plot design with 3 reps.	[9]
Keszthely tillage experiment HU4	Hungary	46° 44' 5" N 17° 13' 47" E	1972	MAT: 10.5°C MAP: 683 mm (Dfb)	Eutric Cambisol	Arable Tillage (Conventional or Shallow disking)	0–10 10–20	Randomized block design with 4 reps.	[10]

Table S2 Overview of methods used to determine chemical, physical, and biological soil quality indicators as measured in the framework of the European project of the European project “Interactive Soil Quality Assessment in Europe and China for agricultural productivity and environmental resilience” (iSQAPER) and used in Bongiorno et al.^[1,11,12] and Bongiorno et al. (unpublished data). Properties in bold were used for the current study, adapted from Bongiorno et al.^[11]

Properties	Methodology	Unit	Laboratory of analysis
Chemical properties			
Total organic carbon	SIST ISO 10694: Soil quality - Determination of organic and total carbon after dry combustion (“elementary analysis”)	%	University of Ljubljana
Total nitrogen	SIST ISO 13878:1999: Soil quality - Determination of total nitrogen content by dry combustion (“elementary analysis”)	%	University of Ljubljana
pH	CaCl ₂ determination- SIST ISO 10390:2006: Soil quality - Determination of pH	–	University of Ljubljana
Cation exchange capacity	ISO 13536:1995: Soil quality - Determination of the potential cation exchange capacity and exchangeable cations using barium chloride solution buffered at pH 8.1	cmol _c ·kg ⁻¹ soil	University of Ljubljana
Plant available phosphorus (P ₂ O ₅)	ÖNORM L 1087 - modification: ammonium lactate extraction	mg·kg ⁻¹ soil	University of Ljubljana
Available phosphorus (P-Olsen)	SIST ISO 11263-1996	mg·kg ⁻¹ soil	University of Ljubljana
Plant available potassium (K ₂ O)	ÖNORM L 1087 - modification: ammonium lactate extraction	mg·kg ⁻¹ soil	University of Ljubljana
Exchangeable magnesium, calcium, sodium, and potassium (Mg ²⁺ , Ca ²⁺ , Na ⁺ , K ⁺)	Ammonium acetate extraction; Soil survey laboratory methods manual, 1992	mg·kg ⁻¹ soil	University of Ljubljana
Physical properties			
Water stable aggregates	Wet sieving method modified as in Öhlinger & Kandeler ^[13]	mg·kg ⁻¹ soil	FiBL
Bulk density	Volumetric assessment with ring	g·cm ⁻³	Field assessment by LTE owners
Silt, clay and sand	SIST ISO 11277:2011: Soil quality - Determination of particle size distribution in mineral soil material - Method by sieving and sedimentation	%	University of Ljubljana
Penetration resistance	Pressure needed to insert penetrometer in the soil	Mpa	Field assessment by LTE owners
Water holding capacity	Calculated with a pedotransfer function using the proportions of clay, silt and total organic carbon ^[14]	%	Wageningen University & Research
Biological properties			

Microbial biomass carbon and nitrogen	Fumigation extraction method ^[15]	mg·kg ⁻¹ soil	University of Trier
Soil respiration	Incubation of soil at 25°C for 72 h in thermostat bath	μg·h ⁻¹ ·g ⁻¹ soil	University Miguel Hernandez
Earthworm abundance and biomass	Hand sorting from 30×30×30 cm ³ monolith	g·m ⁻² (number and fresh weight)	Field assessment by LTE owners
Tea bag decomposition	Tea bag incubation (tea bag index) ^[16]	% (mass loss)	Field assessment by LTE owners

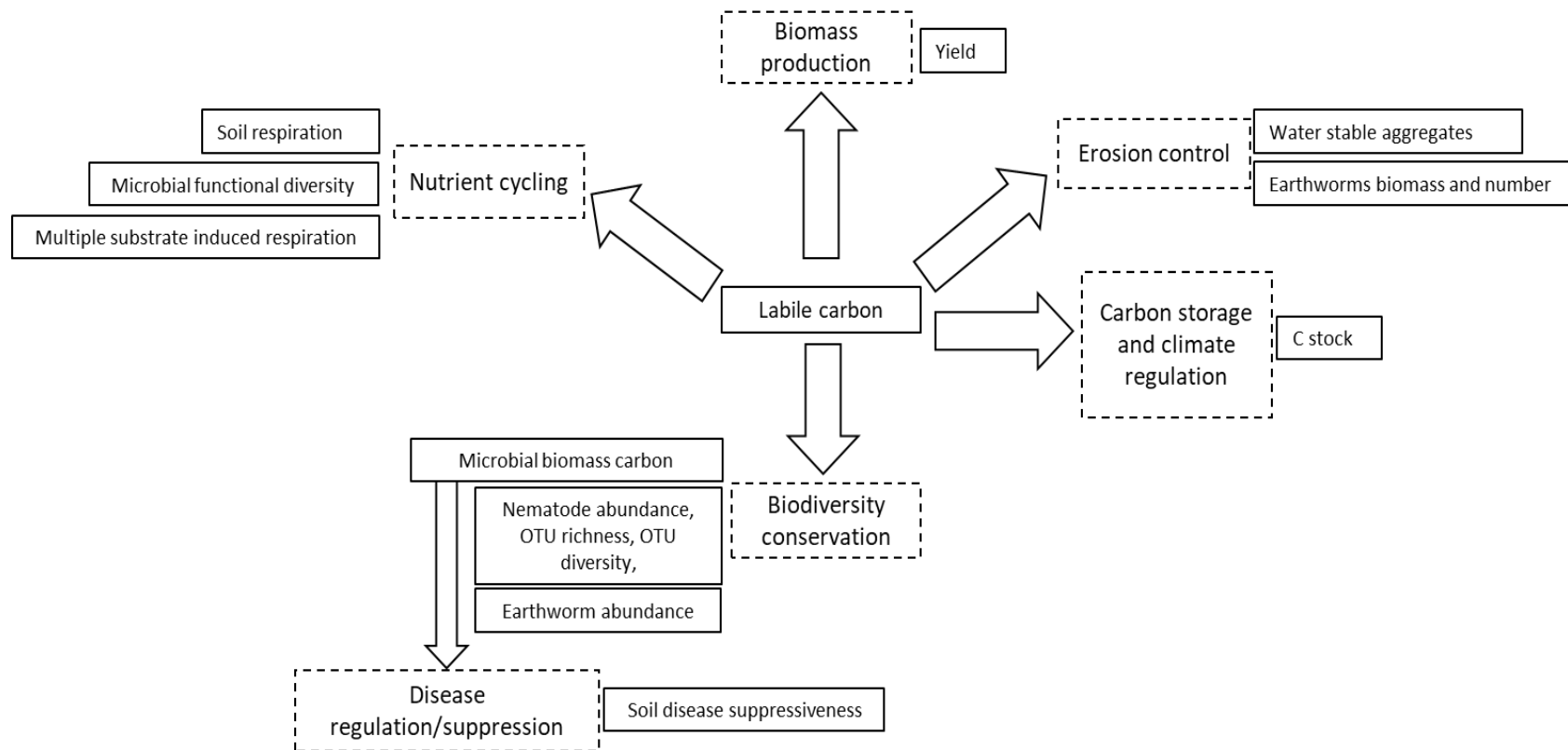


Fig. S1 *A priori* model showing the hypothesized relationships between labile carbon and various soil processes and ecosystem services for the structural equation model. Dashed boxes represent ecosystem services, and the boxes adjacent to the dashed boxes give the properties used as proxies for these ecosystem services.

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