EXCELLENCE FOR SUSTAINABILITY

Research Institute of Organic Agriculture
Forschungsinstitut für biologischen Landbau
Institut de recherche de l’agriculture biologique






Carbon levels in agricultural soils under organic and non-organic management – a meta analysis

Andreas Gattinger

Round Table on Organic Agriculture and Climate Change

Contents

Contents

Aims of the meta study

- Quantifying carbon contents, stocks and sequestration rates in soils under organic and non-organic management

- Analysing factors influencing soil carbon levels:
  - Continent
  - Climate
  - Landuse (arable, grassland, horticulture-orchard, horticulture-vegetables)
  - Management (ORG, Non-ORG)

Contents

Literature search, data acquisition and processing

1. Literature search
2. Literature review/evaluation
3. If positive: integration into data matrix and parametrisation
4. Descriptive and explorative statistics with *SPSS* software
5. Meta analysis with *Comprehensive Meta Analysis* software

1. Literature search: Details

- **Online searches in:**

  CAB Abstracts http://www.cabi.org
  Google Scholar http://scholar.google.com
  ISI Web of Knowledge (including Web of Knowledge with Conference Proceedings, BIOSIS Previews) http://apps.isiknowledge.com
  Scopus http://www.scopus.com
  SCIRUS http://www.scirus.com/
  AGRICOLA http://agricola.nal.usda.gov
  Scielo http://www.scielo.org
  GeoRef database http://www.ovid.com/
  ScienceDirect http://www.sciencedirect.com
  Organic Eprints http://www.orgprints.org

using the search terms (abstract/title/keywords):
“carbon AND soil AND conventional”

1. Literature search: Details

- **Evaluation of the references in the 5 most cited (suitable) papers**
- **Because of poor data sources from developing (southern) countries:**
  - Recognised experts of that field of research were contacted to contribute further ideas on resource identification and invited to share relevant publications or data
  - „Call for soil carbon data" by poster at „Tropentag 2010" in Zürich
- **Literature search is open until manuscript is submitted**

2. Literature review/evaluation

Qualifying criteria:

- only reviewed papers: a) peer-reviewed scientific journals b) conference proceedings/book chapters/dissertations
- Only studies based on pairwise comparisons (under similar site conditions) for organic and conventional farming practices are considered
- In 1 case a fertiliser experiment is included (manure vs. mineral) all other studies are based on farming system comparisons

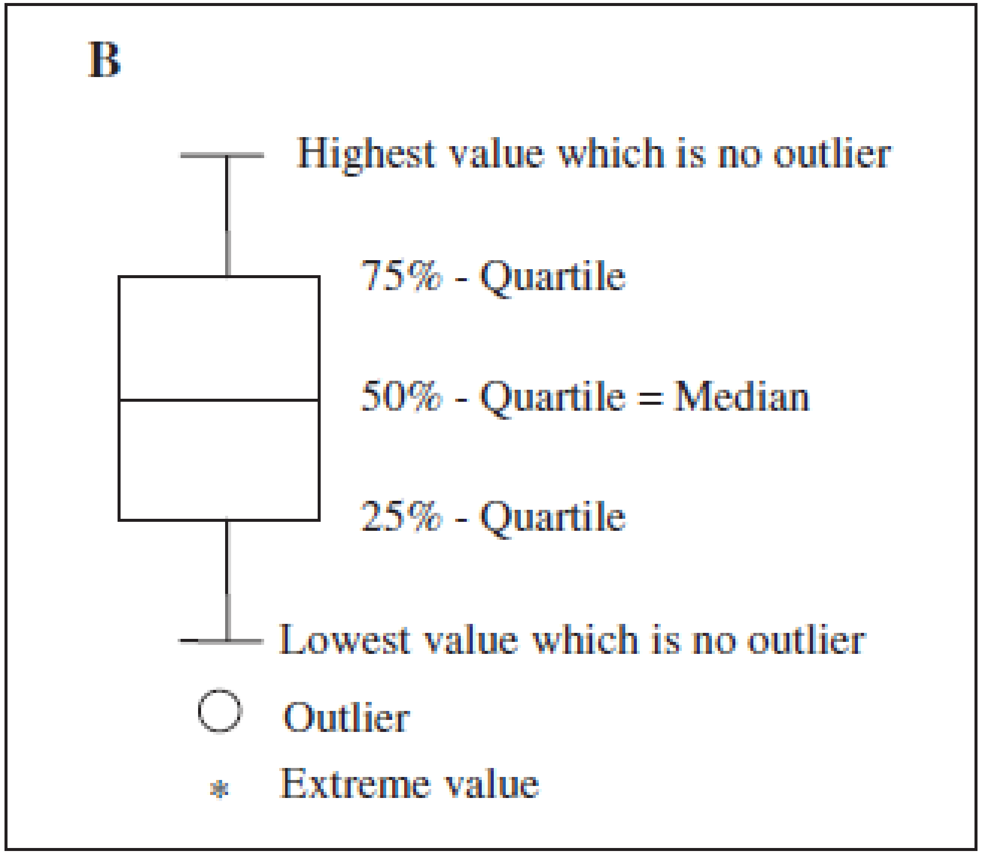
Contents

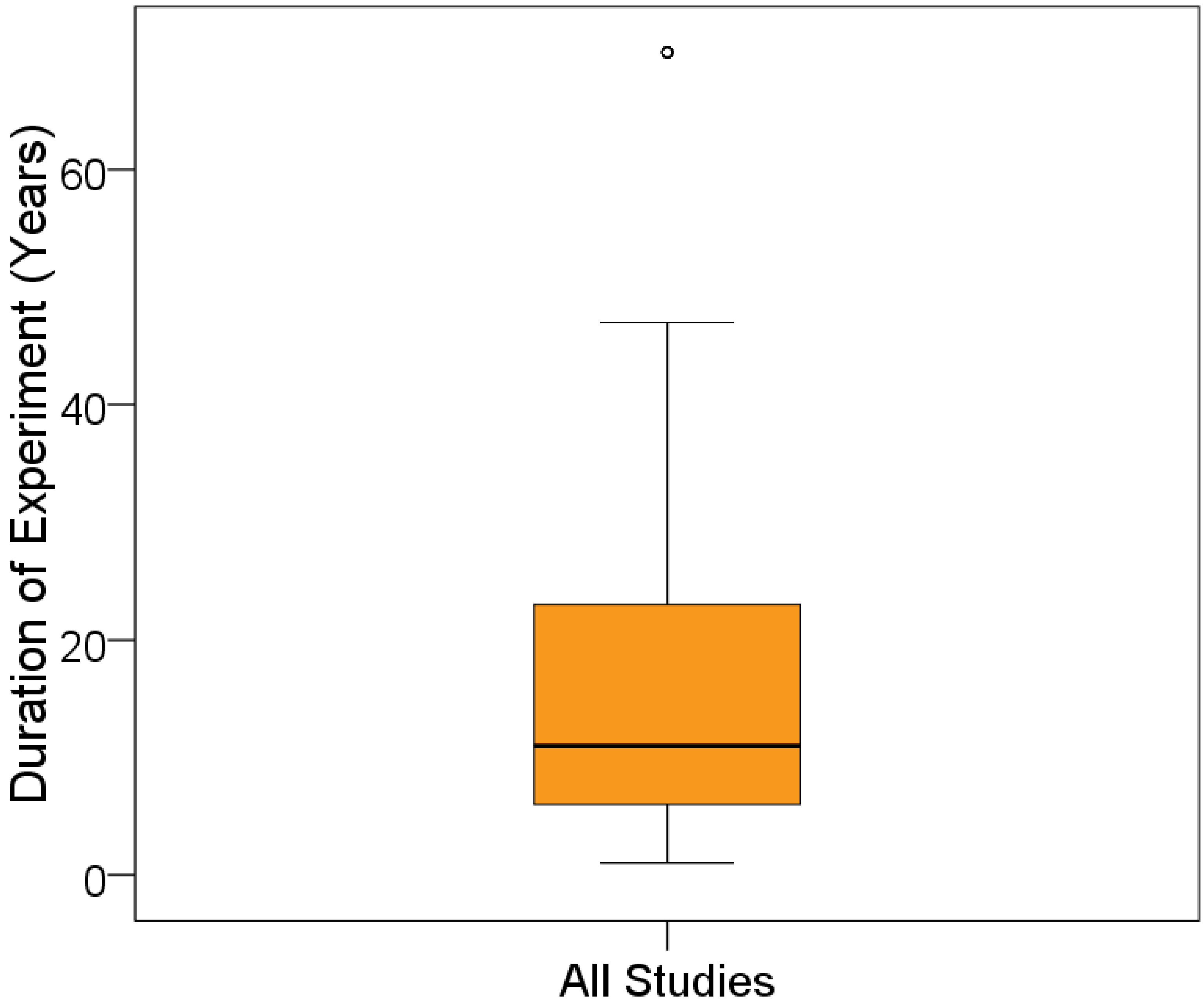
Soil carbon under organic farming

- Number of publications included:
  45 in total for meta-study consisting of:
  - 37 peer-reviewed paper from scientific journals
  - 8 conference proceedings/book chapters
- These 45 publications are based on pair-wise system comparisons. These are all from 44 field research projects consiting of:
  - 21 long-term plot experiments
  - 5 field trials
  - 18 farm comparisons
- These 45 publications based on 44 field research projects encompass 280 data sets (lowest data aggregation level: general statistics) based on 2477 samples (meta analysis)

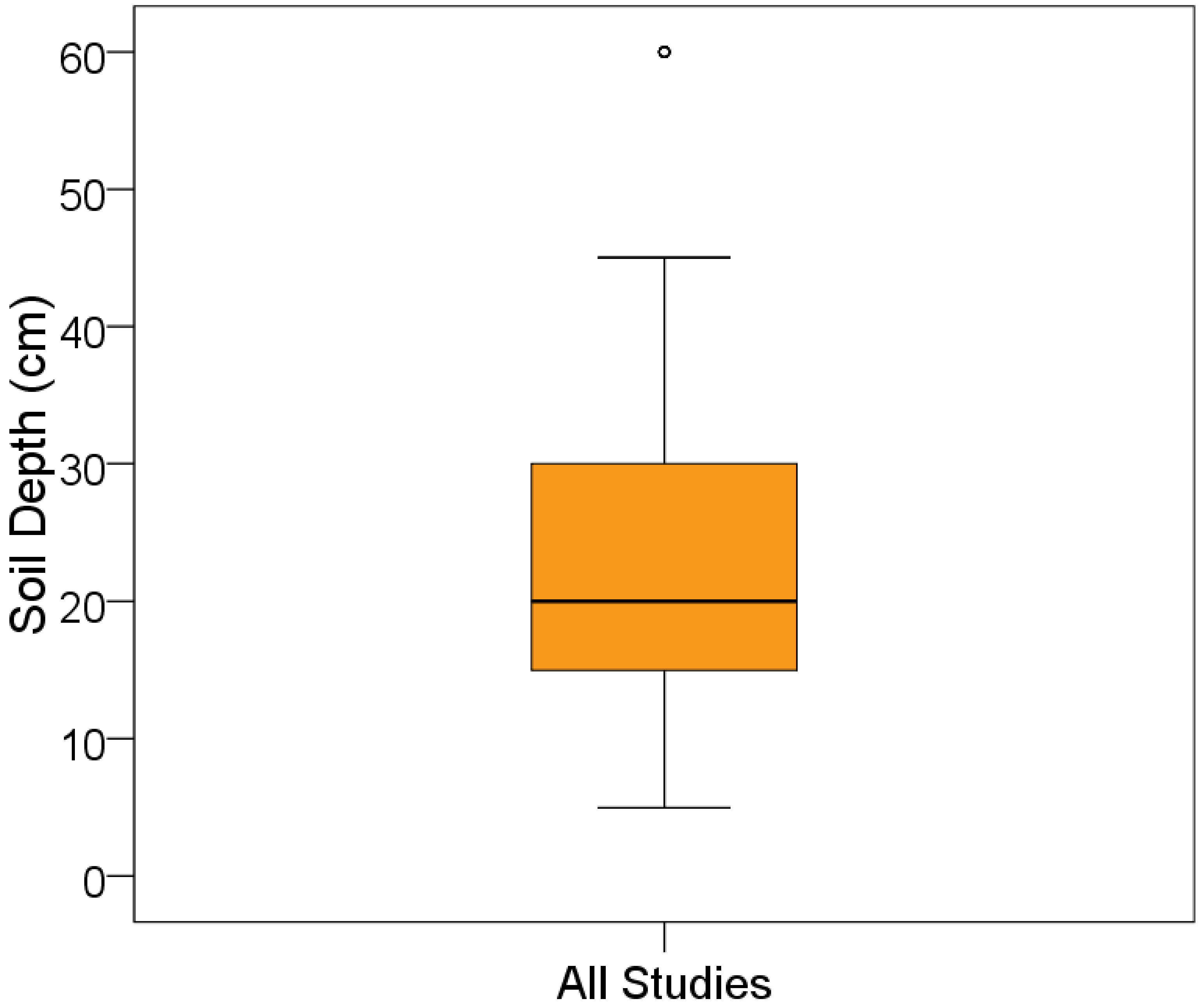
See also excel list for summary of the data matrix

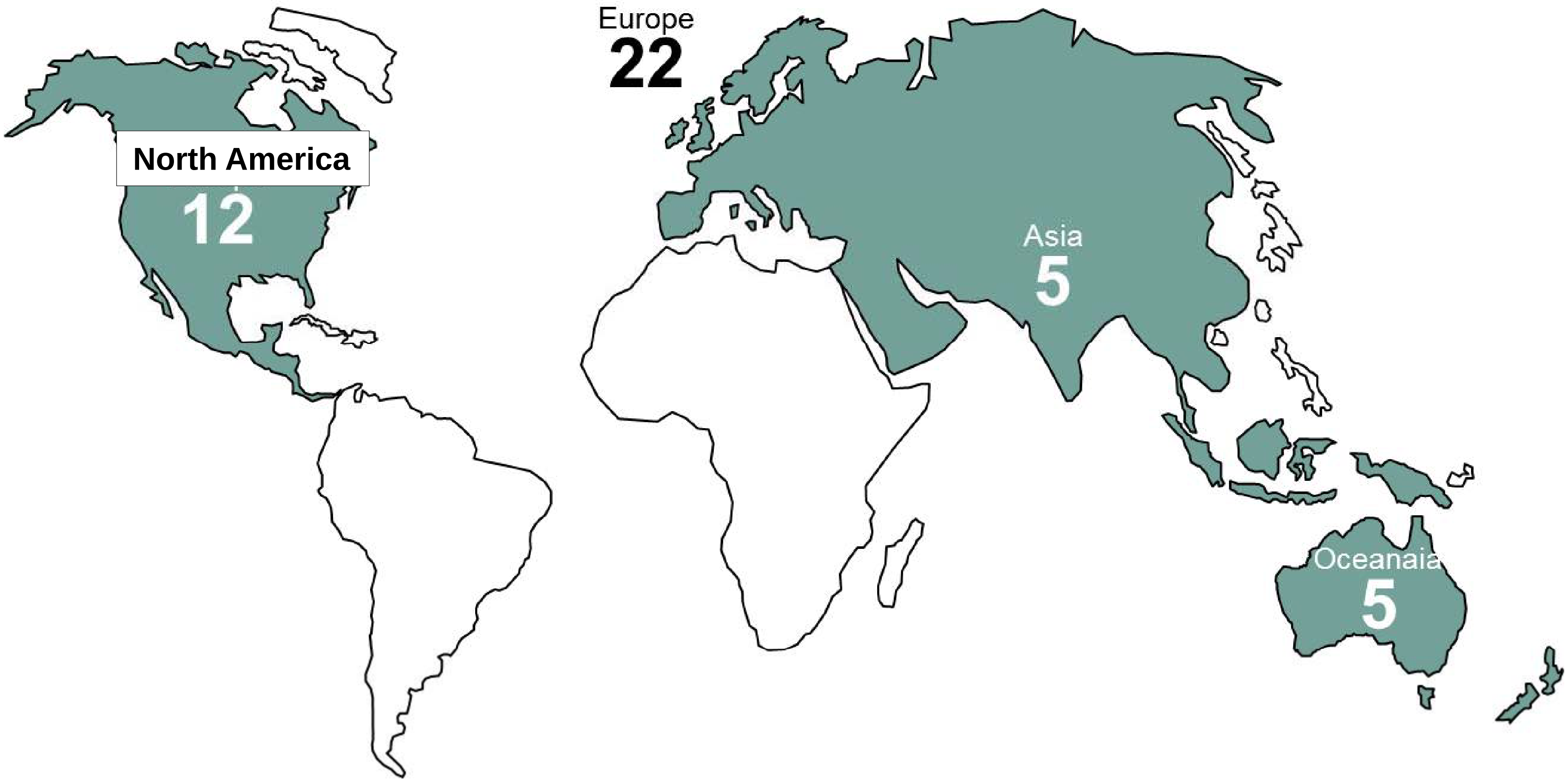
What is a box plot?



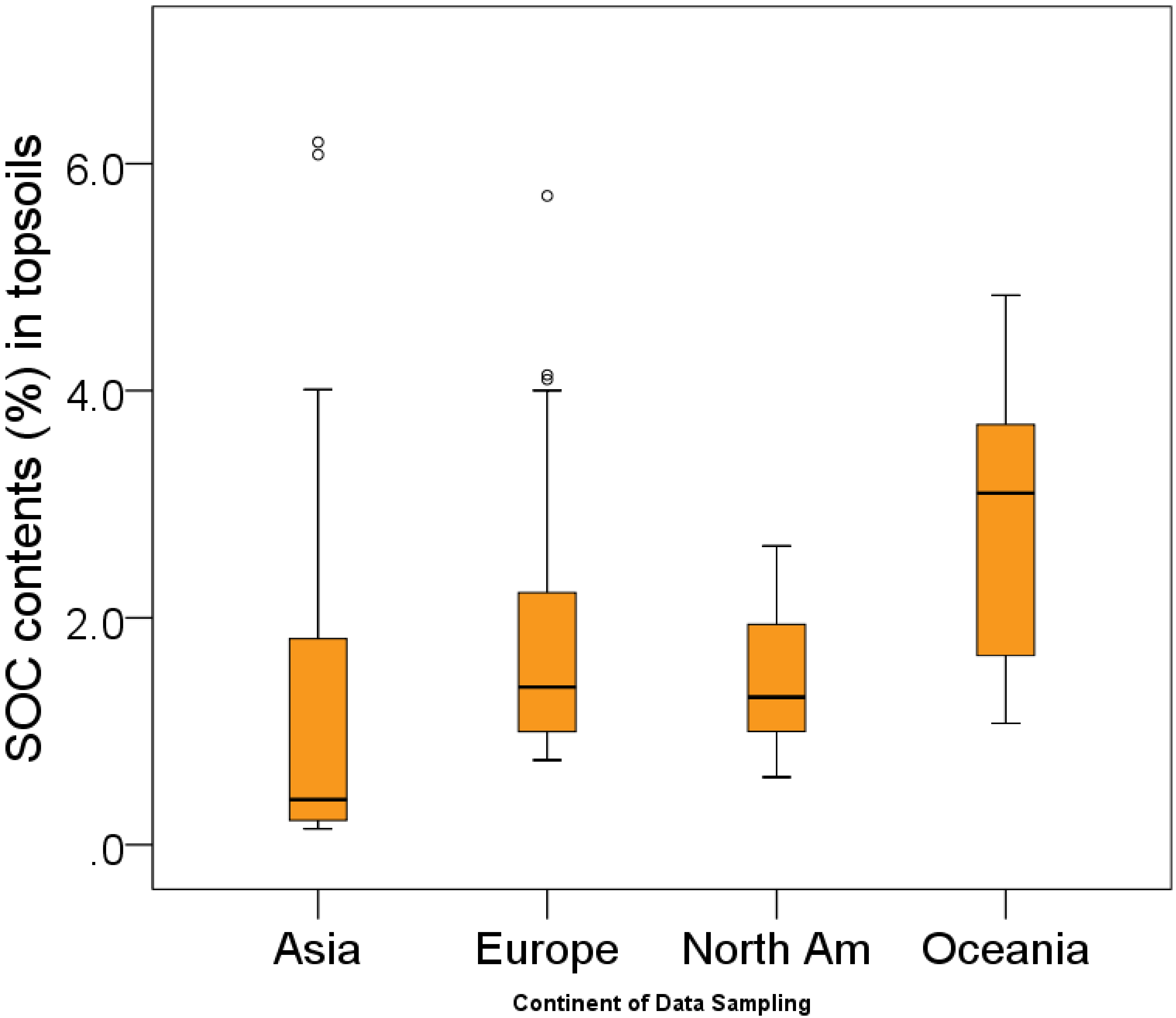


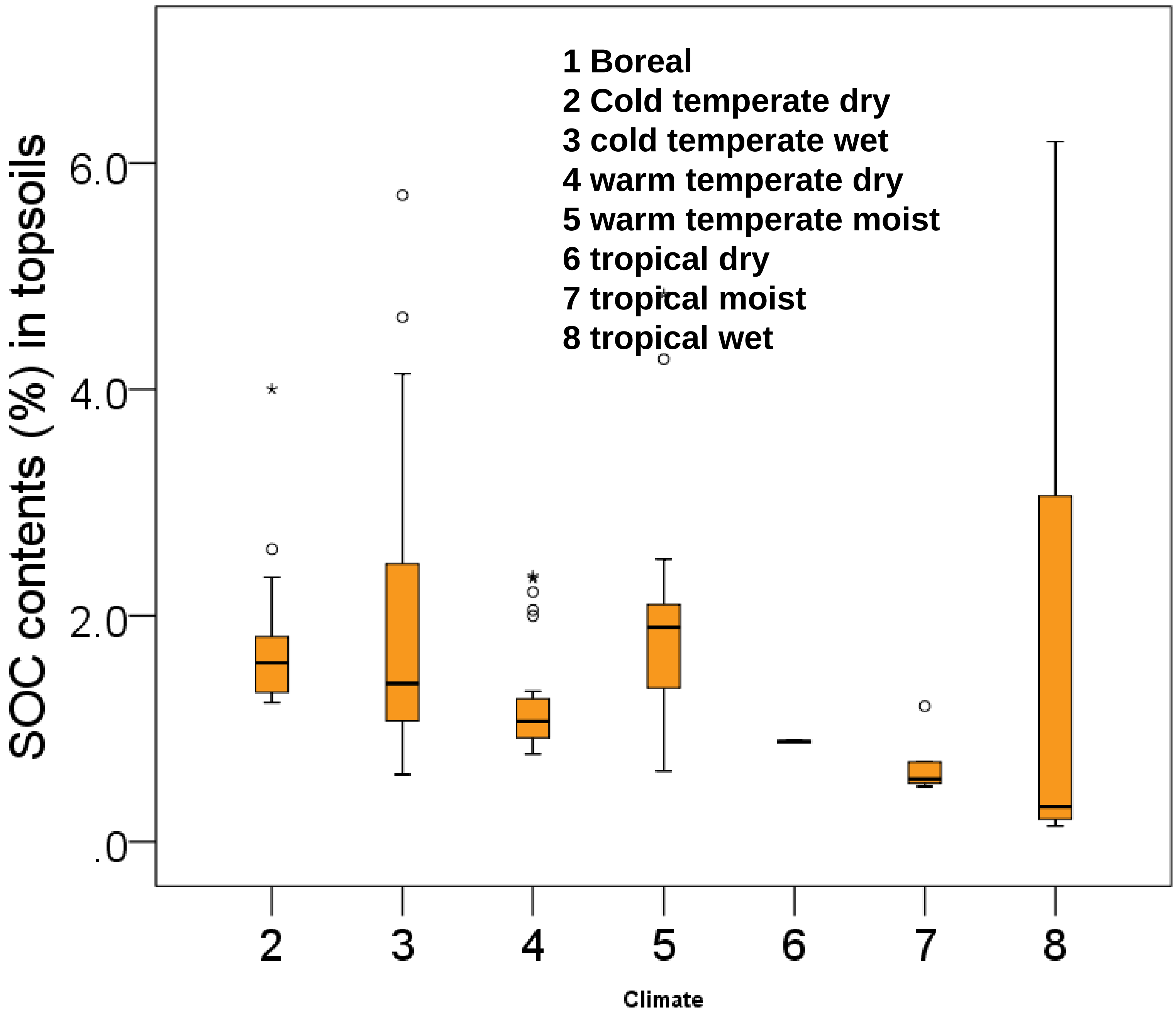
Duration of Experiment (Years)
60
40
20
0
All Studies

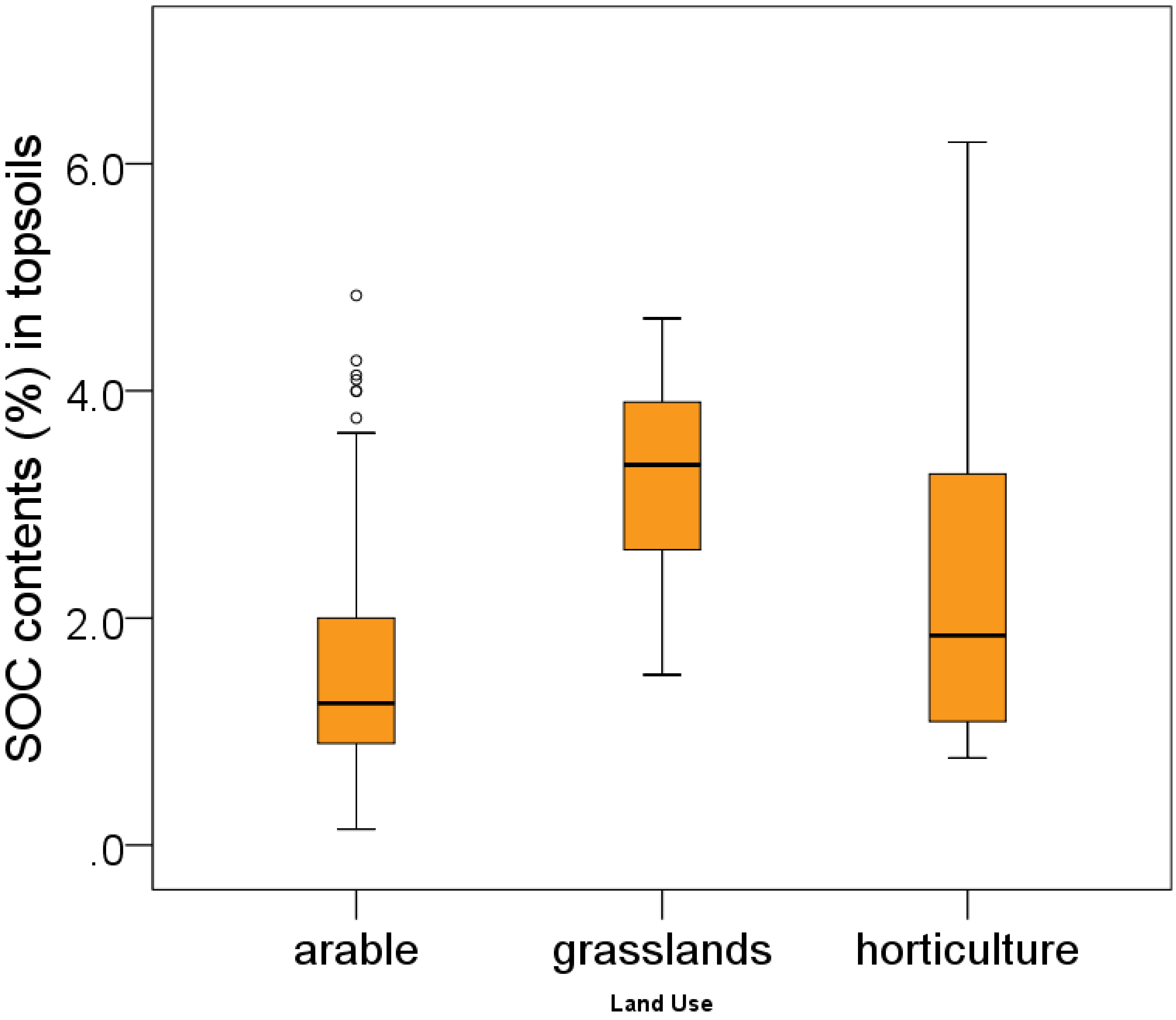

Soil Depth (cm)
60
50
40
30
20
10
0
All Studies


Europe
22
North America
12
Asia
5
Oceanaia
5

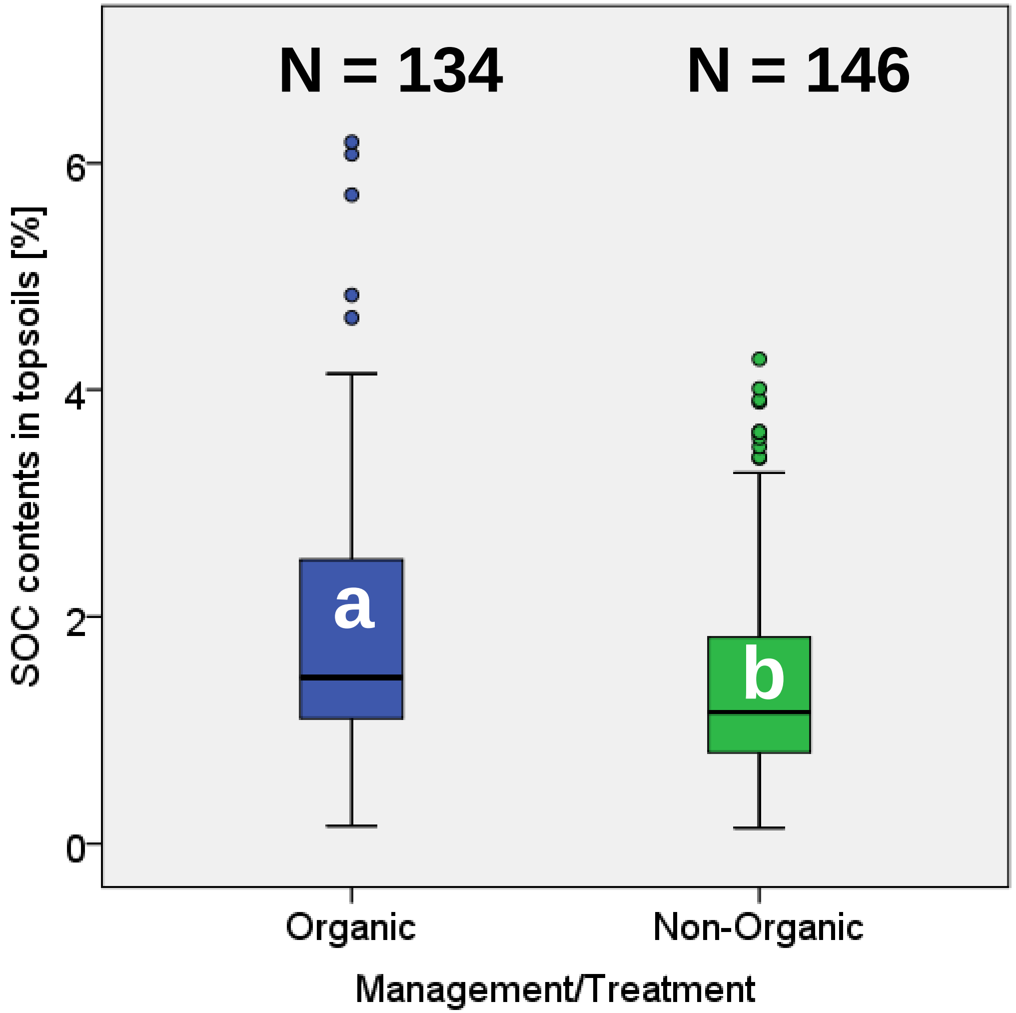
Contents


SOC contents (%) in topsoils
6.0
4.0
2.0
.0
Asia
Europe
North Am
Oceania
Continent of Data Sampling

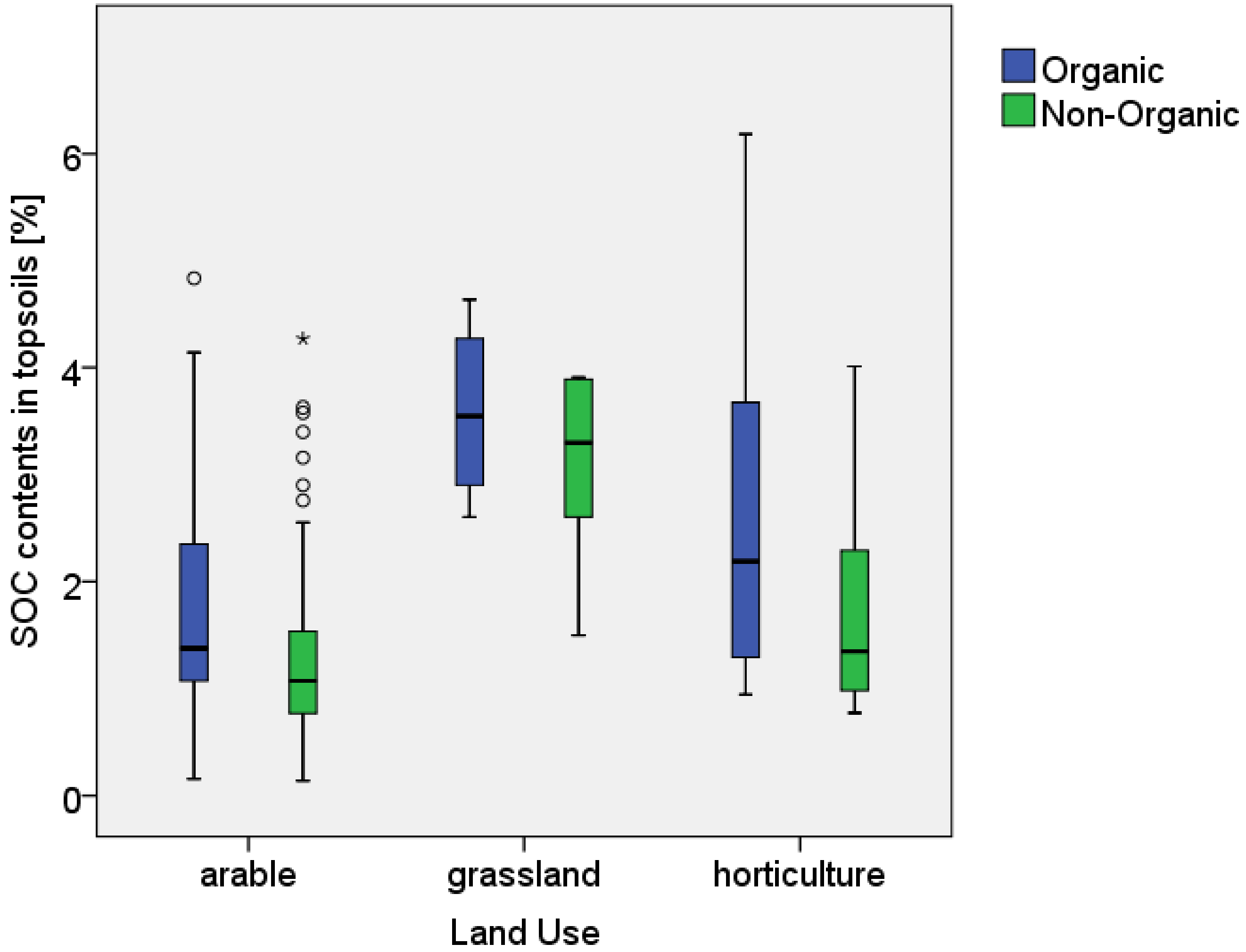

1 Boreal
2 Cold temperate dry
3 cold temperate wet
4 warm temperate dry
5 warm temperate moist
6 tropical dry
7 tropical moist
8 tropical wet
SOC contents (%) in topsoils
6.0
4.0
2.0
.0
2
3
4
5
6
7
8
Climate



FiBL www.fibl.org



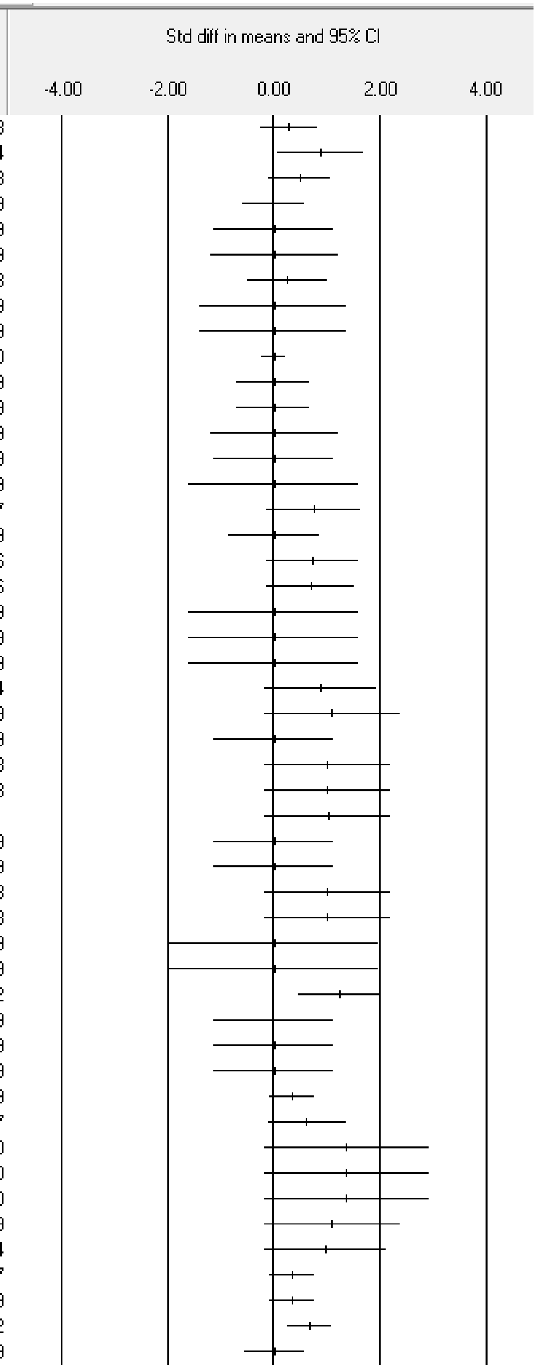
<u>In average (median):</u>
ORG: 1.47%
non-ORG: 1.16%



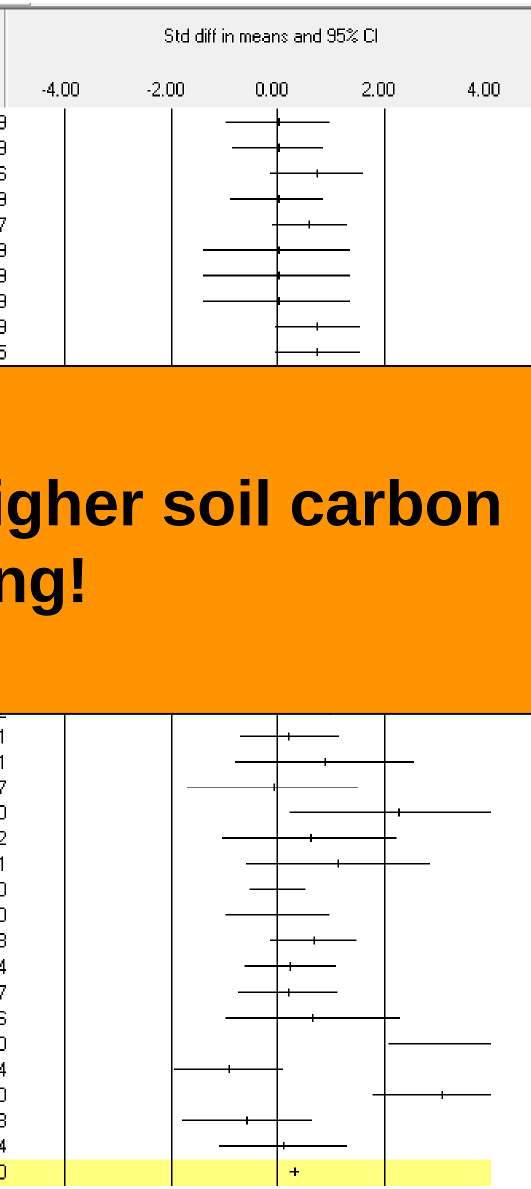
Organic
Non-Organic
SOC contents in topsoils [%]
0
2
4
6
arable
grassland
horticulture
Land Use

Contents

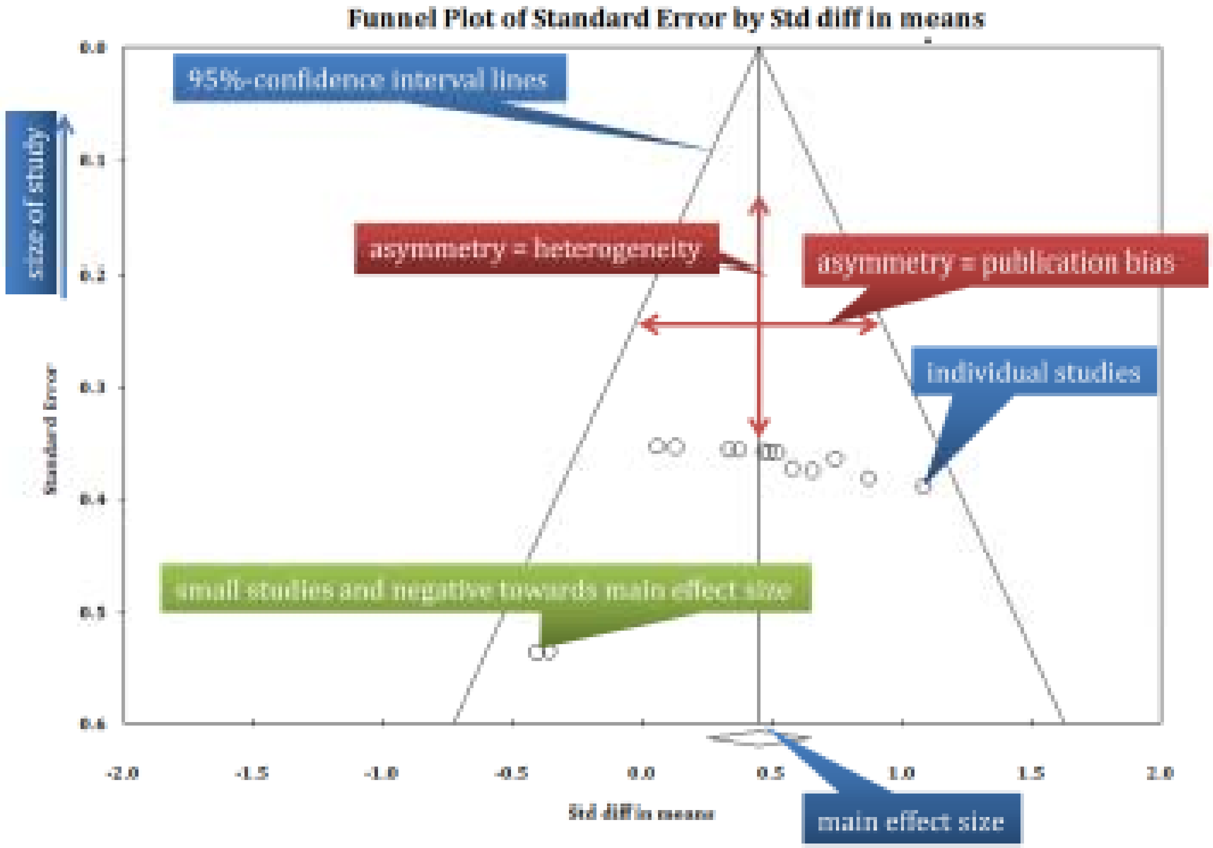
Study name	Subgroup within study	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Canali 2005	Citrus	0.285	0.274	0.075	-0.251	0.821	1.042	0.298
Canali 2009	Citrus	0.871	0.410	0.168	0.067	1.676	2.123	0.034
Clark et al 1998	0-15 cm	0.495	0.299	0.090	-0.092	1.082	1.653	0.098
Clark et al 1998	15-30 cm	-0.000	0.296	0.088	-0.580	0.579	-0.001	0.999
Delate and Cambardella, 2004	June 1998	0.001	0.577	0.333	-1.131	1.132	0.001	0.999
Delate and Cambardella, 2004	November 1998	0.001	0.612	0.375	-1.199	1.201	0.001	0.999
Derrick & Dumaresq 1999	Org-to-Con-Comparison	0.269	0.387	0.150	-0.490	1.027	0.694	0.488
Eltun et al 2002	Arable	0.001	0.707	0.500	-1.385	1.387	0.001	0.999
Eltun et al 2002	Forage	0.001	0.707	0.500	-1.385	1.387	0.001	0.999
Eyhorn et al. 2007	Cotton	0.006	0.115	0.013	-0.219	0.231	0.050	0.960
Fliessbach et al 2007	Fertilization manure level 1	0.000	0.354	0.125	-0.693	0.693	0.001	0.999
Fliessbach et al 2007	Fertilization manure level 2	0.000	0.354	0.125	-0.693	0.693	0.001	0.999
Fraser et al 1988	0-7.5 cm	0.001	0.612	0.375	-1.199	1.201	0.001	0.999
Fraser et al 1988	15-30 cm	0.001	0.577	0.333	-1.131	1.132	0.001	0.999
Friedel et al 2000	Org-to-Con-Comparison	0.001	0.816	0.667	-1.599	1.601	0.001	0.999
Garcia et al 1989	Dyn-to-Con-Comparison	0.754	0.455	0.207	-0.137	1.644	1.658	0.097
Hepperly et al 2006	Year 1981	0.001	0.433	0.188	-0.848	0.849	0.001	0.999
Hepperly et al 2006	Year 2002	0.744	0.446	0.199	-0.131	1.618	1.667	0.096
Kahle 2005	Org-to-Con-Comparison	0.701	0.421	0.177	-0.123	1.525	1.667	0.096
Kirchmann et al 2007	Arable Production Conversion	0.001	0.816	0.667	-1.599	1.601	0.001	0.999
Kirchmann et al 2007	Grassland Conversion	0.001	0.816	0.667	-1.599	1.601	0.001	0.999
Kirchmann et al 2007	Org-to-Con-Comparison	0.001	0.816	0.667	-1.599	1.601	0.001	0.999
Kong et al 2005	Org-to-Con-Rotation-Comparison	0.895	0.535	0.287	-0.154	1.945	1.672	0.094
Kramer et al. 2006	Apple	1.110	0.653	0.426	-0.170	2.390	1.700	0.089
Kukal 2009	Maize-Wheat 0-15 cm	0.001	0.577	0.333	-1.131	1.132	0.001	0.999
Kukal 2009	Maize-Wheat 15-30 cm	1.017	0.605	0.366	-0.168	2.202	1.682	0.093
Kukal 2009	Maize-Wheat 30-45 cm	1.017	0.605	0.366	-0.168	2.202	1.682	0.093
Kukal 2009	Maize-Wheat 45-60 cm	1.024	0.605	0.366	-0.162	2.209	1.692	0.091
Kukal 2009	Rice-Wheat 0-15 cm	0.001	0.577	0.333	-1.131	1.132	0.001	0.999
Kukal 2009	Rice-Wheat 15-30 cm	0.001	0.577	0.333	-1.131	1.132	0.001	0.999
Kukal 2009	Rice-Wheat 30-45 cm	1.017	0.605	0.366	-0.168	2.202	1.682	0.093
Kukal 2009	Rice-Wheat 45-60 cm	1.017	0.605	0.366	-0.168	2.202	1.682	0.093
Liebig & Doran 1999	Giltner	0.001	1.000	1.000	-1.959	1.961	0.001	0.999
Liebig & Doran 1999	Medina	0.001	1.000	1.000	-1.959	1.961	0.001	0.999
Lytton-Hitchins et al 1994	Dyn-to-Con-Comparison	1.244	0.399	0.159	0.463	2.026	3.120	0.002
Marinari et al 2005	April 2001	-0.001	0.577	0.333	-1.132	1.131	-0.001	0.999
Marinari et al 2005	November 2001	0.001	0.577	0.333	-1.131	1.132	0.001	0.999
Marinari et al 2005	September 2000	0.001	0.577	0.333	-1.131	1.132	0.001	0.999
Marriott & Wander 2006	Org-to-Con-Comparison	0.360	0.218	0.048	-0.068	0.788	1.650	0.099
Mazzoncini et al 2010	Org-to-Con-Comparison	0.621	0.374	0.140	-0.112	1.354	1.662	0.097
Melero et al 2006	Broad bean June 2000	1.374	0.786	0.618	-0.167	2.915	1.748	0.080
Melero et al 2006	Melons/W. Melons Aug 2001	1.374	0.786	0.618	-0.167	2.915	1.748	0.080
Melero et al 2006	Melons/W. Melons May 2000	1.374	0.786	0.618	-0.167	2.915	1.748	0.080
Melero et al 2007	Crop rotation lentil	1.110	0.653	0.426	-0.170	2.390	1.700	0.089
Melero et al 2007	Crop rotation wheat	0.969	0.580	0.336	-0.167	2.105	1.672	0.094
Mulla et al 1992	Backslope	0.353	0.212	0.045	-0.064	0.769	1.660	0.097
Mulla et al 1992	Footslope	0.350	0.212	0.045	-0.066	0.767	1.650	0.099
Mulla et al 1992	Topslope	0.672	0.217	0.047	0.247	1.096	3.099	0.002
Oberholzer et al 2000	Org-to-IP-Comparison	0.000	0.289	0.083	-0.565	0.566	0.001	0.999



Study name	Subgroup within study	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Petersen et al 1997	Org-to-Con-Comparison	0.001	0.500	0.250	-0.979	0.981	0.001	0.999
Pimentel et al 2005	Year 1981	0.001	0.433	0.188	-0.848	0.849	0.001	0.999
Pimentel et al 2005	Year 2002	0.744	0.446	0.199	-0.131	1.618	1.667	0.096
Rasul and Tapa 2004	Comparison Pair	0.001	0.447	0.200	-0.876	0.877	0.001	0.999
Raupp 2001	Darmstadt	0.598	0.361	0.130	-0.109	1.304	1.658	0.097
Raupp 2001	Darmstadt High Fert	0.001	0.707	0.500	-1.385	1.387	0.001	0.999
Raupp 2001	Darmstadt Low Fert	0.001	0.707	0.500	-1.385	1.387	0.001	0.999
Raupp 2001	Darmstadt Medium Fert	0.001	0.707	0.500	-1.385	1.387	0.001	0.999
Reganold 2010	0-10 cm	0.738	0.405	0.164	-0.056	1.533	1.821	0.069
Reganold 2010	20-30 cm	0.750	0.406	0.165	-0.046	1.545	1.847	0.065
Blaise 2006	Nagpur	0.207	0.473	0.223	-0.719	1.133	0.438	0.661
Capriel 1991	Farm Pair 1	0.885	0.856	0.732	-0.792	2.562	1.035	0.301
Capriel 1991	Farm Pair 2	-0.085	0.817	0.667	-1.686	1.516	-0.105	0.917
Capriel 1991	Farm Pair 3	2.264	1.046	1.094	0.214	4.314	2.165	0.030
Capriel 1991	Farm Pair 4	0.615	0.836	0.698	-1.022	2.253	0.736	0.462
Capriel 1991	Farm Pair 5	1.125	0.879	0.772	-0.598	2.847	1.280	0.201
Dilly 2001	Arable	0.000	0.271	0.073	-0.531	0.531	0.000	1.000
Dilly 2001	Grassland	0.000	0.500	0.250	-0.980	0.980	0.000	1.000
Drinkwater et al 1995	Org-to-Con-Comparison	0.685	0.414	0.172	-0.127	1.496	1.653	0.098
Gosling & Shepherd 2005	Org-to-Con-Comparison	0.225	0.434	0.189	-0.626	1.076	0.518	0.604
Grandy 2007	Org-to-Con-Comparison	0.190	0.472	0.223	-0.735	1.116	0.403	0.687
Granstedt et al 2008	Org-to-Con-Comparison	0.653	0.838	0.702	-0.989	2.296	0.780	0.436
Moeskops 2010	Cisarua1	4.064	1.011	1.022	2.083	6.045	4.021	0.000
Moeskops 2010	Cisarua2	-0.901	0.522	0.273	-1.925	0.122	-1.727	0.084
Nguyen et al 1995	Org-to-Con-to-Dyn-Comparison	3.084	0.662	0.438	1.787	4.381	4.661	0.000
Pulleman et al 2003	0-10 cm	-0.573	0.623	0.389	-1.795	0.649	-0.919	0.358
Pulleman et al 2003	10-20 cm	0.105	0.613	0.375	-1.096	1.306	0.171	0.864
		0.308	0.043	0.002	0.224	0.391	7.187	0.000

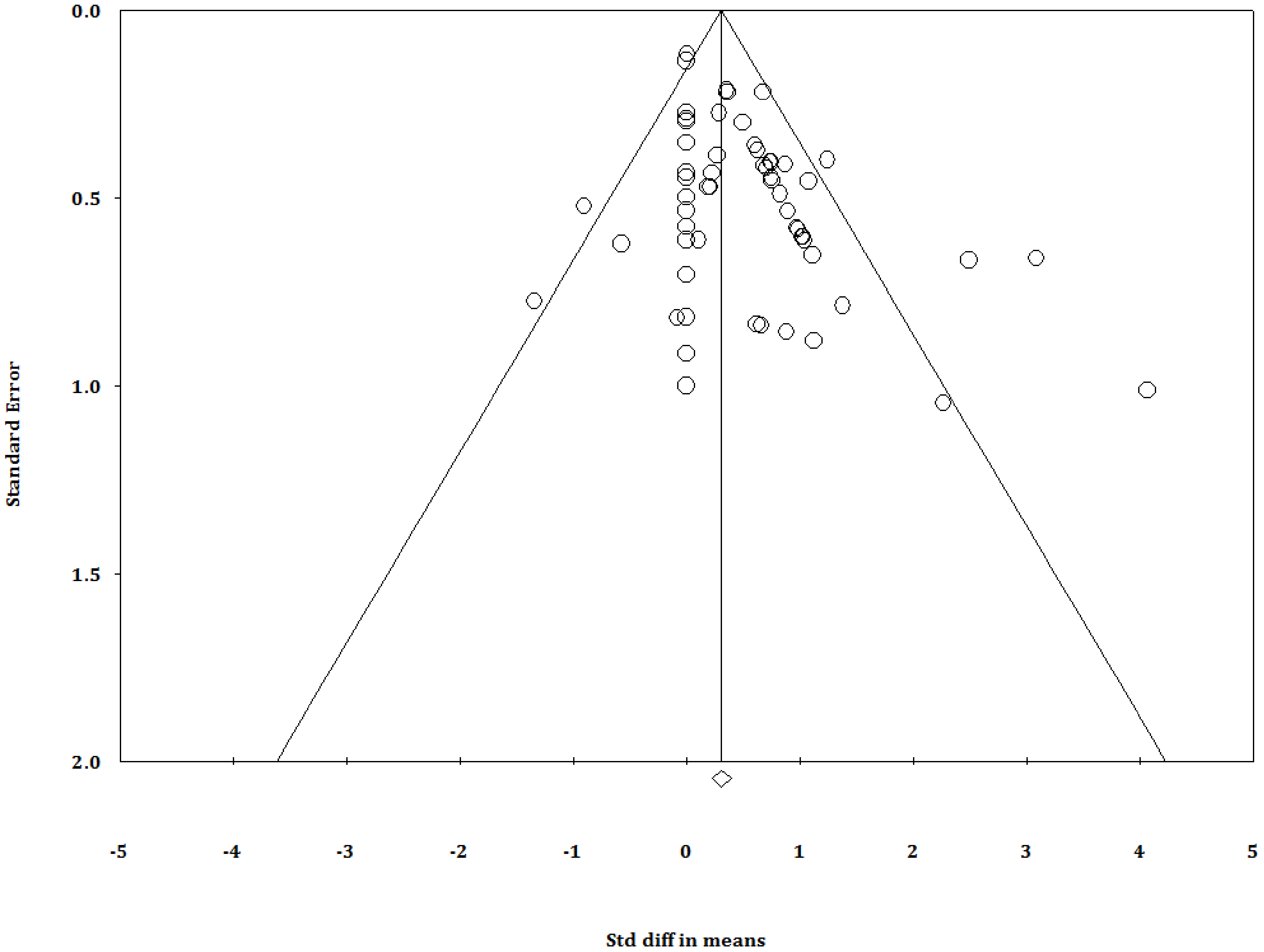


There is strong scientific evidence for higher soil carbon levels under organic farming!



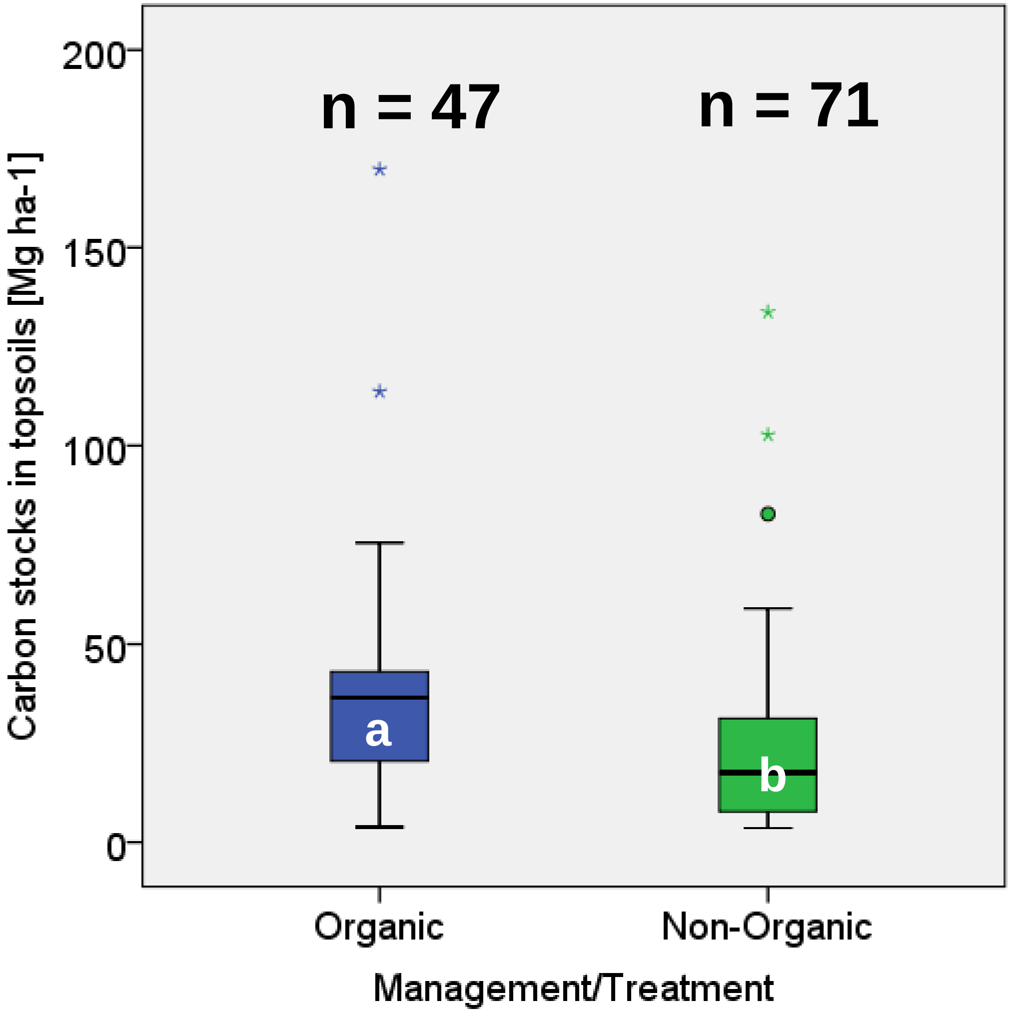
Funnel Plot of Standard Error by Std diff in means
95%-confidence interval lines
size of study
asymmetry = heterogeneity
asymmetry = publication bias
individual studies
small studies and negative towards main effect size
main effect size
Standard Error
Std diff in means
0.0
0.1
0.2
0.3
0.4
0.5
0.6
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0

Funnel Plot of Standard Error by Std diff in means



Preliminary results: C stocks

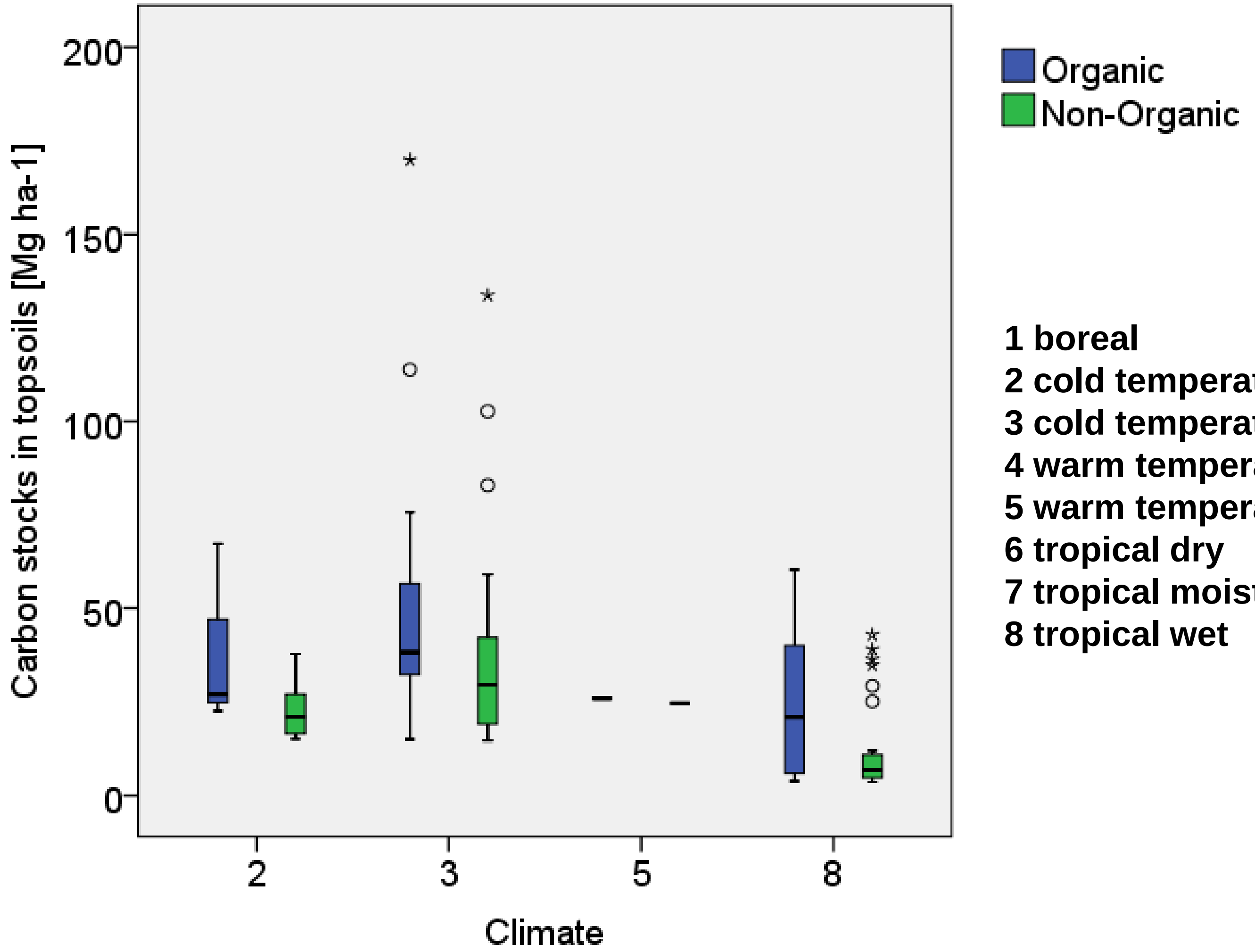
12 publications, 118 data sets, n = 463



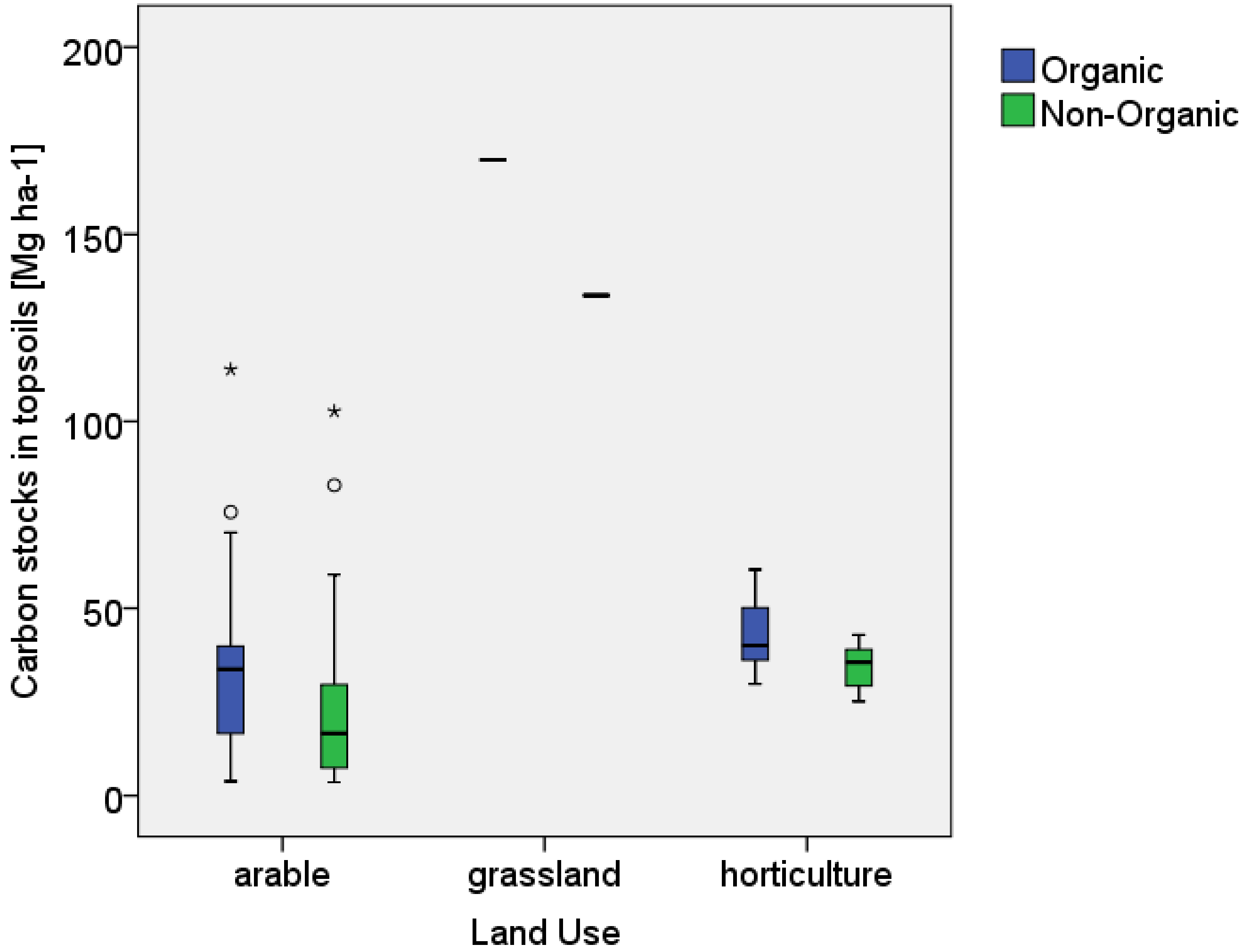
<u>in 25 cm soil horizon:</u>

ORG: 37.4 t C/ha

non-ORG: 26.7 t C/ha



1 boreal
2 cold temperate dry
3 cold temperate wet
4 warm temperate dry
5 warm temperate moist
6 tropical dry
7 tropical moist
8 tropical wet


200
150
100
50
0
Carbon stocks in topsoils [Mg ha-1]
arable
grassland
horticulture
Land Use
Organic
Non-Organic

Contents

Tests of Between-Subjects Effects

Dependent Variable:Soil organic carbon as concentration (in %, usually mean)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	231.596[a]	43	5.386	12.372	.000
Intercept	262.930	1	262.930	603.961	.000
Management	4.130	1	4.130	9.487	.002
Climate	24.784	6	4.131	9.488	.000
Land Use	3.623	2	1.811	4.161	.017
Continent	21.196	3	7.065	16.229	.000
Error	102.741	236	.435		
Total	1078.401	280			
Corrected Total	334.337	279			

a. R Squared = .693 (Adjusted R Squared = .637)

Contents

Summary and conclusions

- There is strong scientific evidence for higher carbon levels in soils under organic farming. Influencing factors will be further elucidated.
- There is a lack of soil carbon data for developing countries: no data from Africa and Latin America!
- Only limited data on C stocks. Further attempts will be made for getting more reliable data, important to enable calculation of C sequestration rates.

cknowledgements

Mercator Foundation Switzerland: "Meta-analysis on soil carb

FAO Natural Resources Management and Environment Departr

"Data consensus and data gaps related to soil carbon sequest

potential of organic crop and livestock systems."

I. Data consensus and data gaps related to soil carbon sequestration potential of organic crop and livestock systems

- Data collection
- Data analysis
- Data gaps and methodological difficulties
- Preliminary results
- Way forward (further analysis, publication, GHG study)

- **Data collection:** see FiBL and SEAE approach on qualifying criteria and data matrix, RTOACC members will get an update of included and excluded studies on farming system comparisons along with data/study request form

- **Data analysis:** see FiBL and SEAE approach (meta-analysis)

- **Preliminary results**: as shown by FiBL and SEAE with reference to Leifeld & Fuhrer (2010)

- **Data gaps and methodological difficulties:**
  - poor data availability for developing countries
  - poor data availabilty for rice production systems and grassland (including pastoralism)
  - missing values in published studies, i.e. soil bulk density for C stock calculation, t_0 values for precise sequestration rate determination, clay contents/soil texture

Carbon sequestration under organic farming

(Leifeld & Fuhrer 2010; peer-reviewed: 32 studies; 68 comparisons)

Table 2 Overview of key data for the comparison of organic versus conventional farming including relative SOC change rates per year

Experiment setup (from-to)[a]	Duration (years)[d]	Depth (cm)[e]	Annual change[f] (percent)					N[h]
			Total	Experiment type[g]		SOC measure		
				Plot	Farm	Concentration	Mass	
con–con	12, 13.1	20, 20	−0.16	−0.16	–	−0.21	−0.03	14
	(3–27)	(7.5–30)	(0.45)	(0.45)		(0.64)	(0.19)	
con–org	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
							5)	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
							4)	

[a] con–con c … ith either
(b) change r … s without
reference to …

[b] Relative t …

[c] Relative t …

[d] Median, r …

[e] Median, mean (min and max)

[f] Mean carbon change rate per year (percentage of reference) relative to starting value or conventional control, 1 SE in parenthesis

[g] *Plot* controlled field experiment, *Farm* comparison of adjacent farms

[h] Number of data sets for three experimental set-ups

- **2.2% annual C_{org} increase under organic, no increase under conventional farming**
- **differences due to often disproportionate application of organic fertiliser**
- **No data from developing country included**

- **Way forward (further analysis, publication, GHG study):**

- Further research is required representing climatic zones, farming systems/cropping systems: pairwise farming system comparisons on soil carbon and GHG emissions using integrative approaches (measuring, process modelling and upscaling)

GHG emissions and organic farming

- Nitrogen fixing legumes, green and organic manuring are key elements in organic crop rotation and bear the potential of N_2O losses when incorporated/applied to the soil.
- Easily available synthetic N fertiliser can be applied according to the plant nutrient status.
- But far more less (non easily availabe organic) N fertiliser are applied in organic farming.
- Hence GHG emission rates (esp. N_2O) are lower under OF practices?

GHG emission from soils under conventional and organic management

- Very poor data base
- Only very few system comparisons based on field measurements

•No evidence-based review yet
•Data only for northern countries
•Request for further field measurements and reliable data sets!!!

GHG emission from soils (CO_2eq/ha) under conventional and organic management (preliminary compilation)

	Type of study	CON > ORG	CON = ORG	CON < ORG
Petersen, 2006: A, DK, FIN, I, GB	Field measurement	x		
Chirinda, 2010: DK	Field measurement		x	
Küstermann, 2008: D	Modelling	x		
Flessa, 2002: D	Field measurement	x*		
Sehy, 2003: D	Field measurement	x*		
Lynch, 2008: Canada	Field measurement	x		
Nemecek, 2005: CH	Life cycle assessment	x**		
Hansen, 2008: N	Field measurement	x		

* no difference when related to unit of yield
** lower GHGE in ORG when related to unit of yield

II. Organic farming systems' potential for accreditation of a methodology for the carbon market

- Types of carbon credits (CDM, VCM)
- Project Types
- New and revised methodologies
- Challenges and strengths
- Agriculture and climate change mitigation institutions
- Way forward (implementation)