Quality Assessment of Meta-analyses on Soil Organic Carbon

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Why is this topic important for us?

- Meta-analyses are getting more and more **popular**
- Many of them have **low quality**!
- **Soil organic carbon (SOC)** prominent topic

What is the problem?

- Researchers are missing **expertise**
- **No guidelines** suited to needs of agriculture or soil science **available**

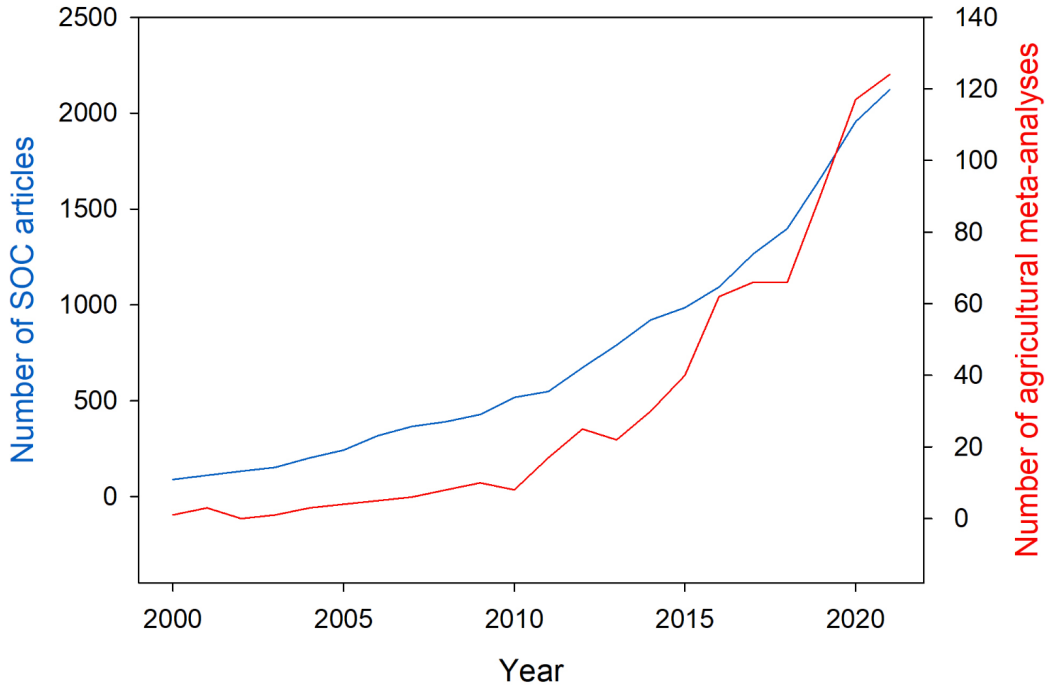


Fig.: Number of SOC articles and agricultural meta-analyses published between 2000 and 2020.

Philibert et al. (2012)
Krupnik et al. (2019)

Specific issues in soil and agricultural meta-analyses

- **Changes in soil are slower**
  than other physiological and biogeochemical changes;
  e.g., changes within plant tissue

- **Complex system**
  not only pedoclimatic conditions influence soil, but also agricultural management practices impact variables of interest

- **Measuring response variables: SOC – BD and pedotransfer**
  soil parameters and indicators: methods available for computation → uncertainty

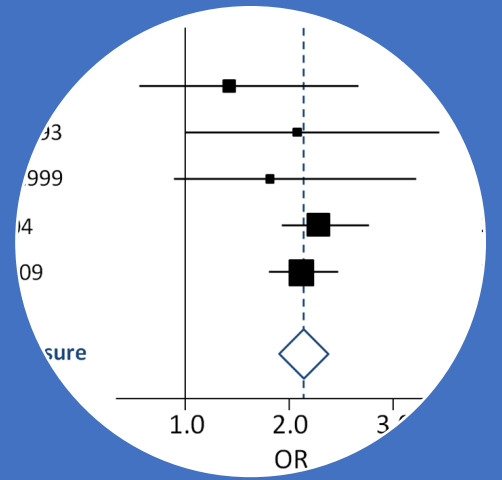
… Soil and agricultural meta-analyses have specific issues which differ from other disciplines!

Aim

Adapt existing guidelines to construct criteria-set for quality assessment in soil science & agriculture

Search available meta-analyses on SOC -

"meta-analysis"; field experiments



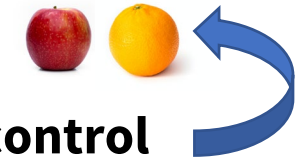
Assess quality of 31 SOC meta-analyses

Quantitative quality criteria-set

+ examples for SOC meta-analysis

Literature search

- Inclusion/exclusion criteria
  Field or lab
- Treatment and **control**
  No-till vs. conventional on SOC
- Moderators
  pH, clay content, climatic zone



Meta-analysis

- Effect size
- Standard deviation extracted
- Weighting: 1/variance
  account for study precision!

Presentation

- Results
- Database
  for each included study:
  mean/SD/N of T and C
  SOC effect size
  moderators

+ Scoring system …. max. 28

Room for improvement in SOC meta-analyses

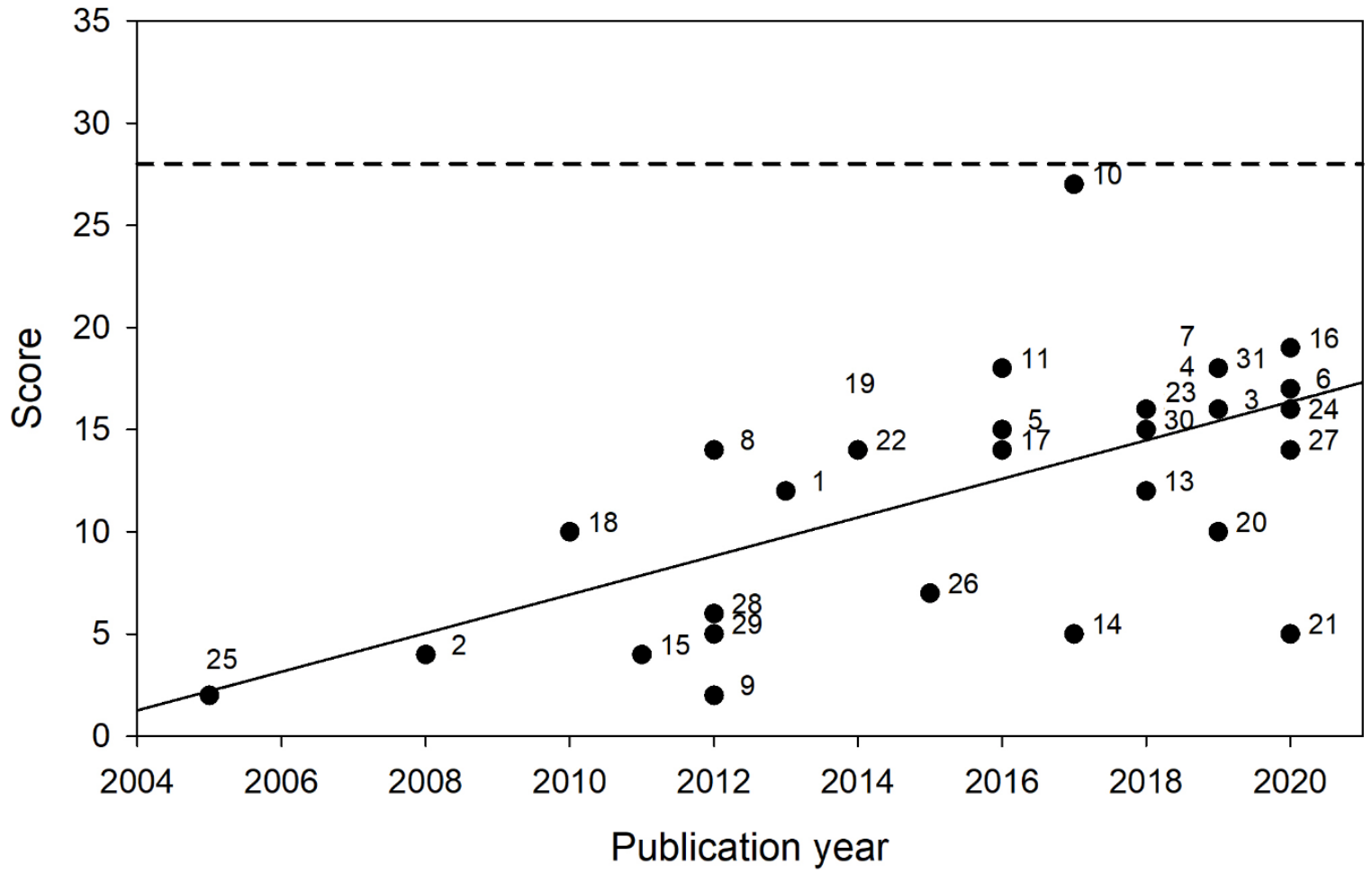
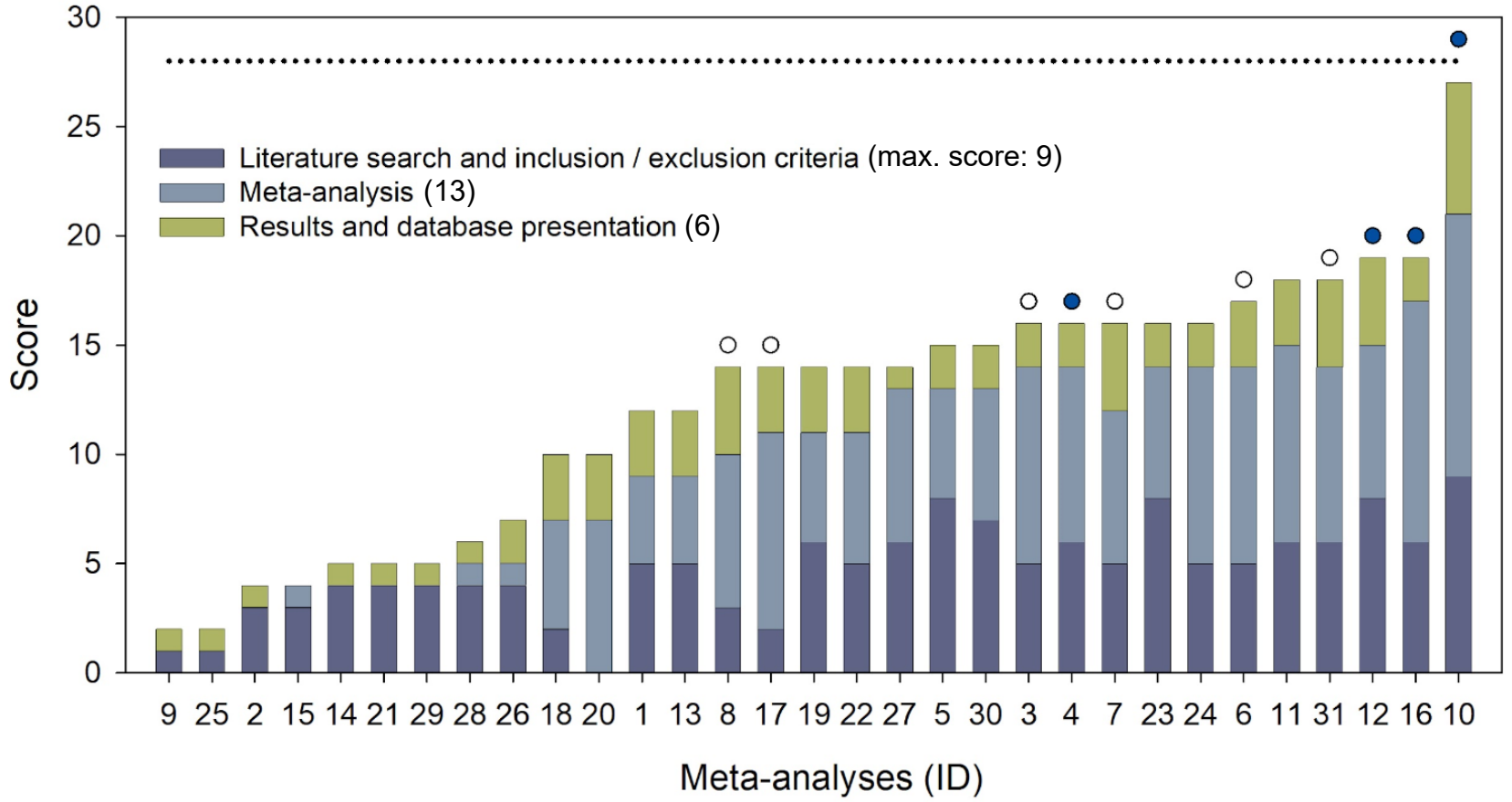


Fig.: Scores of 31 analyzed SOC meta-analyses over time (between 2005-2020)

Biggest issues



- Literature search reporting

- Standard metrics for effect size calculation
- SD extraction
- Weighting by 1/variance
- Non-independence
- Moderator analysis

- Database availability

Fig.: Scores of 31 SOC meta-analyses displayed as scores per group

Full circle: Meta-analysis weighted each study; empty circle: meta-analysis weighted some studies

Management practices?

Management category	Number of times this practice was studied in all 31 meta-analyses	Meta-analysis with the highest score	Score
Tillage	15	Haddaway et al. (2017)	27
		Li et al. (2020)	19
Cover crop	6	Jian et al. (2020)	19
Residue	5	Li et al. (2020)	19
Amendments	4	Chen et al. (2018)	16
Biochar	3	Bai et al. (2019)	17
Organic	6	Garcia-Palacios et al. (2018)	16
Fertilization	4	Han et al. (2016)	18
Diversification	3	McDaniel et al. (2014)	14
Combined	1	Aguilera et al. (2013)	12
High input system	1	Ogle et al. (2005)	2
Set-aside	1	Ogle et al. (2005)	2

Only **1** **excellent** meta-analysis on…

Robust meta-analyses on …



→ but rather **low scores**!
→ Could be improvement

Poor meta-analyses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→ Need **new** meta-analyses!

Semi-robust meta-analyses on…


Hood-Nowotny et al. (2018)

→ Need **improvement**!

Take home messages

- Meta-analysis – follows strict criteria!
- Specific issues in soil and agriculture
- Number of meta-analyses rising - Many do not reach sufficient quality
- Main issues: reporting, effect size, SD extraction, weighting, non-independence, moderators, database
- New or improved meta-analyses are needed on biochar, organic, fertilization, diversification, combined, etc.
- Critically review existing meta-analysis – policy making
- Engage in trainings, use guidelines
- When conducting:
  - ✔ Supervised by expert
  - ✔ Use available guidelines
  - ✔ Tools available that assist SD extraction or SOC calculation from single layers (Acutis et al. 2022, Tadiello et al. 2022)

Thank you for your attention!

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- Acutis, M., Tadiello, T., Perego, A., di Guardo, A., Schillaci, C., & Valkama, E. (2022). EX-TRACT: An excel tool for the estimation of standard deviations from published articles. *Environmental Modelling & Software*, *147*, 105236. https://doi.org/10.1016/j.envsoft.2021.105236
- Tadiello, T., Perego, A., Valkama, E., Schillaci, C., & Acutis, M. (2022). Computation of total soil organic carbon stock and its standard deviation from layered soils. *MethodsX*, *9*. https://doi.org/10.1016/j.mex.2022.101662

- Free to use pictures by unsplash: https://unsplash.com/

Resources

Publications:

- Koricheva, J., Gurevitch, J., 2014. Uses and misuses of meta-analysis in plant ecology. J. Ecol. 102, 828–844. https://doi.org/10.1111/1365-2745.12224
- Gurevitch, J., Koricheva, J., Nakagawa, S., Stewart, G., 2018. Meta-analysis and the science of research synthesis. Nature 555, 175–182. https://doi.org/10.1038/nature25753
- O'Dea, R.E., Lagisz, M., Jennions, M.D., Koricheva, J., Noble, D.W., Parker, T.H., Gurevitch, J., Page, M.J., Stewart, G., Moher, D. and Nakagawa, S. (2021), Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology: a PRISMA extension. Biol Rev. doi:10.1111/brv.12721

Book:

- Koricheva, J., Gurevitch, J., Mengersen, K. (Eds.), Handbook of Meta-Analysis in Ecology and Evolution. Princton University Press, Princeton

Good meta-analysis:

- Haddaway, N.R., Hedlund, K., Jackson, L.E., Kätterer, T., Lugato, E., Thomsen, I.K., Jørgensen, H.B., Isberg, P.E., 2017. How does tillage intensity affect soil organic carbon? A systematic review, Environmental Evidence. BioMed Central. https://doi.org/10.1186/s13750-017-0108-9

Free online trainings:

- https://www.coursera.org/learn/systematic-review
- About systematic reviews, which incorporate meta-analysis: https://systematicreviewmethods.github.io/

Guideline:

- Collaboration for Environmental Evidence. 2018. Guidelines and Standards for Evidence synthesis in Environmental Management. Version 5.0 (AS Pullin, GK Frampton, B Livoreil & G Petrokofsky, Eds) www.environmentalevidence.org/information-for-authors.

Management category	Number of times this practice was studied in all 31 meta-analyses	Meta-analysis with the highest score	Score	Effect size used (standard metrics)	Weighted by 1/variance	SOC response
Tillage	15	Haddaway et al. (2017)	27	Raw mean difference	yes	4.61 Mg ha^{-1}
		Li et al. (2020)	19	ln(R)	yes	11%
Cover crop	6	Jian et al. (2020)	19	ln(R)	yes	30%
Residue	5	Li et al. (2020)	19	ln(R)	yes	13%
Amendments	4	Chen et al. (2018)	16	ln(R)	yes	49%
Biochar	3	Bai et al. (2019)	17	ln(R)	partly	28%
Organic	6	García-Palacios et al. (2018)	16	ln(R)	partly	27%
Fertilization	4	Han et al. (2016)	18	ln(R)	no	-
Diversification	3	McDaniel et al. (2014)	14	ln(R)	no	-
Combined	1	Aguilera et al. (2013)	12	ln(R)	no	-
High input system	1	Ogle et al. (2005)	2	no	no	-
Set-aside	1	Ogle et al. (2005)	2	no	no	-

Group	Quality criteria	Sub-criteria	Is criterion applied in Meta-analysis (and to which extent)	Score	Description	References
Literature search and inclusion / exclusion criteria	1. Literature search	Published literature extracted from	> 4 databases	3	Several databases should be used for extracting published literature to reduce the risk of selection bias	Côté et al. 2013, p. 40
			between 2 and 4 databases	2		
			1 database	1		
			not reported	0		
		Grey literature (unpublished reports and experiments, project reports etc.) included	yes	1	Grey literature maximizes comprehensiveness and reduces risk of bias. Whether conducting a grey literature research is necessary or not is dependent on the meta-analysis itself and needs to be assessed by the authors	Borenstein et al. 2009, p. 280
			no	0		
		Keywords/search string reported	yes	1	The search string(s) used to retrieve literature from different databases should be stated	Côté et al. 2013, p. 43
			no	0		
	2. Authors checked the reference lists of other existing meta-analyses and reviews for available literature		yes	1	Ensures the inclusion of more relevant articles, as occasionally, keyword searching in databases does not provide results for all available literature	Borenstein et al. 2009, p. 278
			no	0		
	3. Inclusion and exclusion criteria reported		yes	1	Inclusion and exclusion criteria should be clearly described and decisions for exclusion of studies should be transparent	Côté et al. 2013, p. 50
			no	0		
	4. Control (C) and treatment (T) described		yes	1	Inclusion of studies on the same research topic and avoiding mixing "apples and oranges"	Stewart et al. 2013, p. 28
			no	0		
	5. Moderators and their range or groups described		yes	1	Defining moderators is essential to evaluate the source of variation across studies. Their range or groups are important to indicate the limits within which moderators were studied	Stewart et al. 2013, p. 32
			no	0		
	6. Effect size	ln(R) (log response ratio)		2	Easily interpretable by back-transformation of ln (R) to a percentage change from the control	Rosenberg et al. 2013, p. 63f
		Raw mean difference (D)		1	Not recommended for meta-analyses having a range of control levels/scales. Example: when SOC stocks are studied, initial values can have a wide range (10-100 t/ha)	Borenstein et al. 2009, p. 21ff
		Standardized mean difference (e.g., Hedges´d)		1	Difficult to interpret; |d | = 0.2 – small effects |d | = 0.5 – moderate effects |d | = 0.8 – large effects	Borenstein et al. 2009, p. 26; Rosenberg et al. 2013, p. 63f

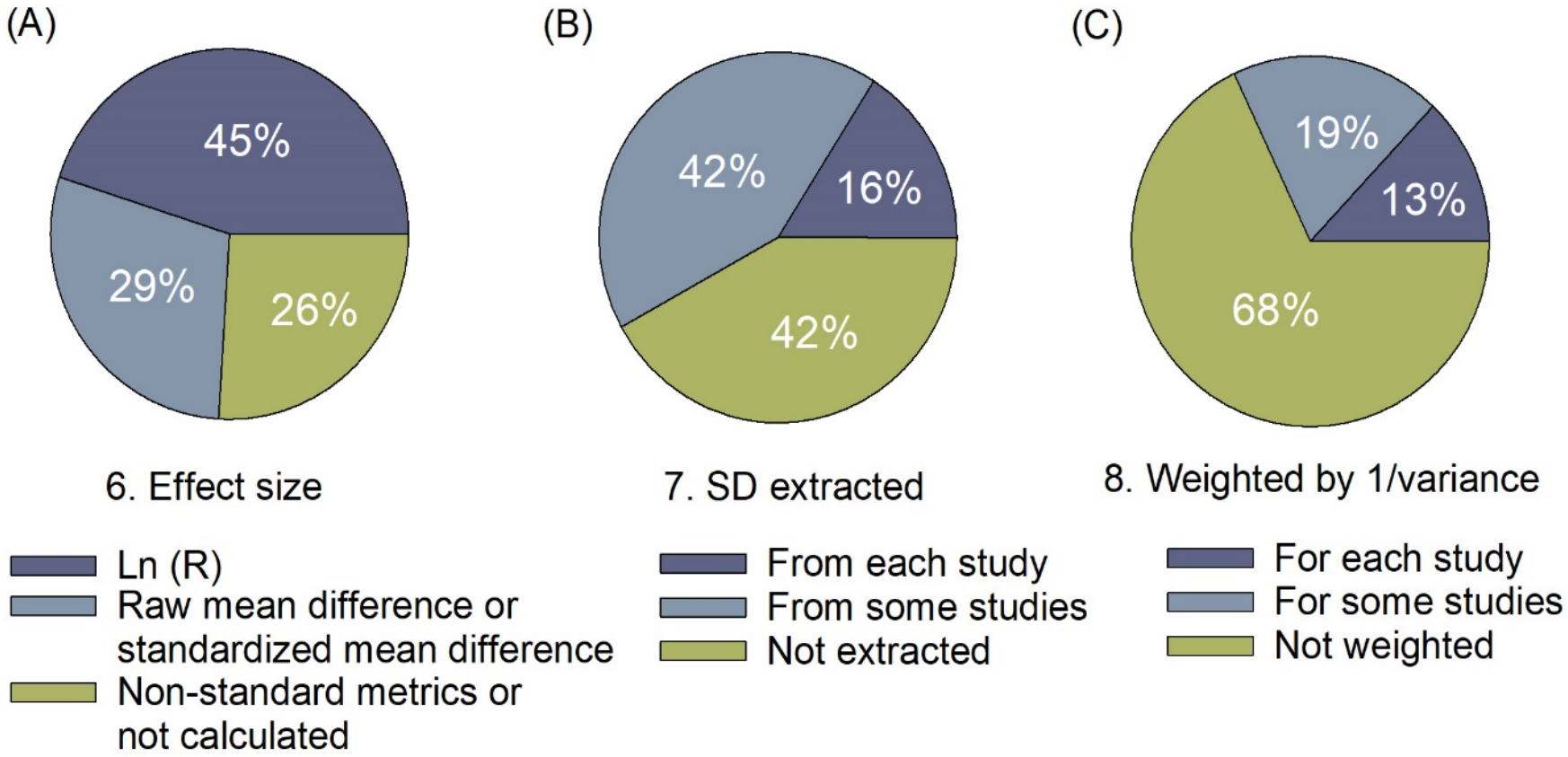
Meta-analysis

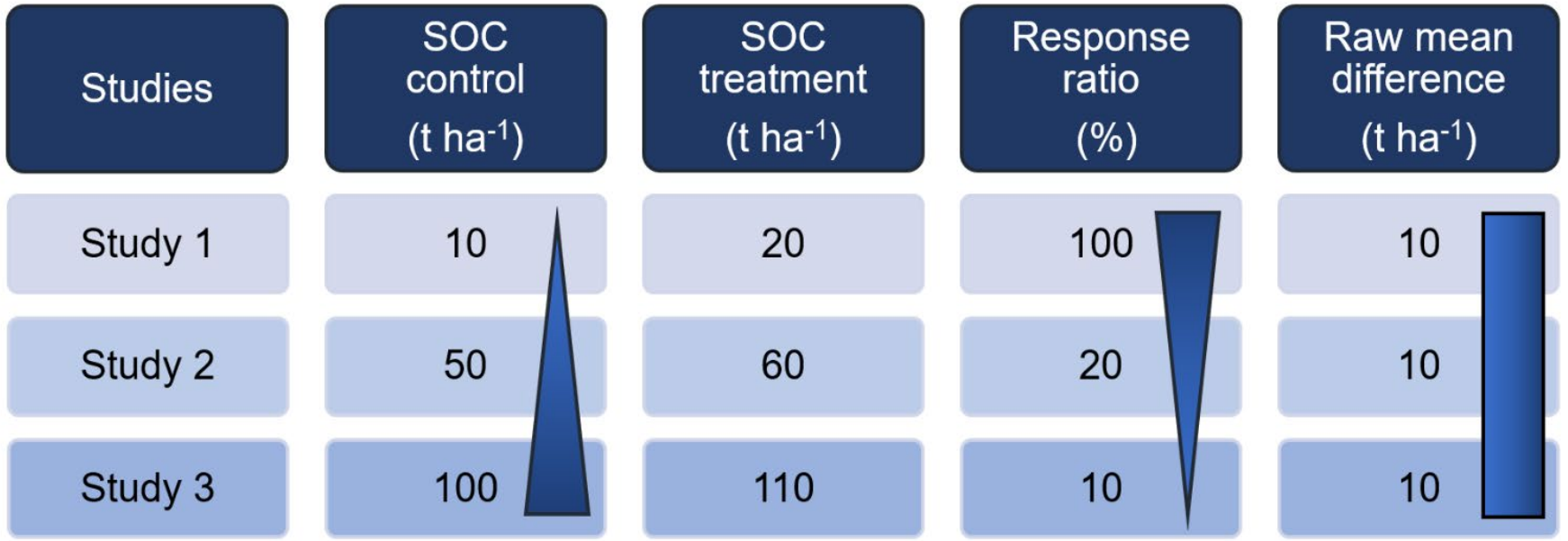
	non-standard metrics used or not calculated		0	Without the calculation of effect sizes, a synthesis does not qualify as a meta-analysis (all following quality criteria of group "Meta-analysis" account for 0)	Koricheva and Gurevitch 2014, p. 840
7. Standard deviation extracted		From each study From some studies Not extracted	2 1 0	Standard deviations need to be extracted from all studies in order to calculate the weight for each study. They should not be estimated	Nakagawa et al. 2017, p.11
8. Studies weighted by 1/variance		For each study For some studies Not weighted / reported	2 1 0	Weighting of studies is only correct when done by the inverse of variance. Meta-analyses that extracted SD only from some studies but weighted by 1/variance did weigh "some studies" or "partly"	Koricheva and Gurevitch 2013, p. 9
9. Subgroup analysis and meta-regression		yes no	1 0	Categorical and/or continuous moderators should be assessed by Q-test	Rosenberg et al. 2000, p. 111f
10. Model used	Random-effect or mixed-effect model Fixed-effect model No model reported		1 0 0	When conducting a meta-analysis in the field of agriculture, the random-effect or mixed-effect model should be chosen, as it acknowledges between-study variation	Mengersen et al. 2013, p. 94
11. Software used for meta-analysis		Meta-analytical software (as MetaWin, Metafor package, etc.) or other software (as SPSS, SAS, Stata, R, etc.) Spreadsheet (as MS Excel) or not reported	1 0	Used software should be stated; when using general statistical analysis software, correct model choice (weighted + random model) and implementation are necessary	Schmid et al. 2013, p. 174
12. Independence of effect sizes		1-2 effect sizes per study/site extracted > 2 effect sizes per study/site extracted	1 0	Effect sizes should be independent. Golden rule: one study or site, one effect size extracted. When several combinations of treatment and control were studied, only one effect size per study/site should be extracted.	Gurevitch and Hedges 1999, p. 1147; Hungate et al. 2009, p. 2009f; Nakagawa et al. 2017, p. 3
13. Response variables and relevant parameters for their calculation were measured		yes no	1 0	Response variables need to be measured in an experiment, not estimated or modelled (e.g., pedotransfer functions only provide estimates for bulk density and therefor introduce the risk of inaccurate calculation of SOC stock contents)	Xu et al. 2015, p. 1574
14. Sensitivity analysis to test robustness of meta-analysis	Outliers and effect size distribution	yes no	1 0	Presence of outliers should be tested and can be identified via effect size distribution in weighted histograms, box-plots, etc.	Rothstein et al. 2013, p. 333
	Detecting publication bias	yes no	1 0	Magnitude of publication bias should be esmimated by funnel plots, Egger's regression or Fail-safe test	Borenstein et al. 2009, p. 291

Results and database presentation	**15. Results presentation in figures and tables**	Summarized effect size and Confidence Intervals	yes	1	Summarized effect size and confidence intervals should be presented in a table or figure	Borenstein et al. 2009, p. 6
			no	0		
		Moderator analysis (sub-group analysis and/or meta-regression)	yes	1	Moderator (covariates) analysis should be presented in form of figures or tables	Borenstein et al. 2009, p. xxii
			no	0		
		Forest plot	yes	1	Forest plots enable the graphical presentation of individual effect sizes of studies and the overall effect size including confidence intervals	Lortie et al. 2013, p. 344f
			no	0		
	16. Description of meta-data		yes	1	A description of meta-data (authors and year plus experimental location, treatments, etc.) in the article or appendix should to be provided as a table	Gonçalves and Musen 2019, p. 2
			no	0		
	17. Full database including most of the following criteria for each study	Article ID and/or first author plus year	Available and includes most of the listed criteria; Article ID and/or first author plus year must be described; either effect size or mean, SD and sample size of T/C must be described	2	Each study should have a distinctive number to allow easy identification	-
					First author and year of publication should be stated	-
		Country/location			Country and exact location of experiment	-
		Control (C)			Measure used as control	-
		Treatment (T)			Measure under investigation	-
		Moderators			Possible moderators (pedo-climatic, experimental conditions, duration of experiments, land use/crops/cropping systems)	Curtis et al. 2013 p. 53
		Means of C/T Standard deviations of C/T Sample sizes C/T			Means, SDs and sample sizes of treatment and control should be stated to allow replication of the meta-analysis	Curtis et al. 2013, p. 52
		Effect size			Calculated effect sizes should be stated	
		Article ID and/or first author plus year Means of C/T Standard deviations of C/T Sample sizes C/T Effect size	Available and includes the listed criteria (either effect size or mean, SD and sample size of T/C must be described)	1	see above in point 17	see above in point 17
			Not available or includes less information than score 1	0	If no database is provided, the meta-analysis is not transparent	Mayo-Wilson and Grant, 2019, p. 481
			Maximum reachable score per meta-analysis:	**28**		

	Inclusion criteria (IC)	Exclusion criteria (EC)
1.	Term meta-analysis used in title, abstract or keywords to describe study style	Systematic reviews and studies using modelling to obtain results
2.	a) Cropland/arable land needs to be part of study; b) other agricultural forms as e.g., agroforestry, paddy soils/upland soils, grassland can be part of study	a) If primary data are from one experimental site (literature not found through database search - not possible to evaluate according to our criteria-set); b) Land-use change studied; c) Cropland/arable land plus forest studied (forest not comparable to arable land)
3.	Effects of management practice on total SOC stocks or concentrations studied	Impact on SOC fractions investigated
4.	Management practice effects on SOC is central topic	Management practice effects on SOC is not a central topic
5.	Field experiments	Laboratory experiments
6.	Conducted on mineral soils	Conducted on organic soils
7.	European studies need to be part of studied experimental sites	Included only non-European experimental sites

Nr.	Category	Description	Meta-analyses
1.	Tillage	no-till, reduced and deep tillage	Aguilera (2013), Angers (2008), Bai (2019), Cooper (2016), Feng (2020), González-Sánchez (2012), Haddaway (2017), Kopittke (2017), Li (2020), Luo (2010), Meurer (2018), Mondal (2020), Ogle (2005), Sun (2020), Virto (2012)
2.	Organic	organic practices	Aguilera (2013), Cooper (2016), García-Palacios (2018), Gattinger (2012), Kopittke (2017), Tuomisto (2012)
3.	Cover crop	cover crops used in crop rotation	Aguilera (2013), Bai (2019), González-Sánchez (2012), Jian (2020), Poeplau (2015), Sun (2020)
4.	Residue	crop residues were either left or removed from the field	Han (2016), Li (2020), Sun (2020), Xia (2018), Xu (2019)
5.	Fertilization	application of organic or mineral fertilizer	Aguilera (2013), Han (2016), Ladha (2011), Xia (2018)
6.	Amendments	application of amendments (e.g., manure)	Aguilera (2013), Chen (2018), Kopittke (2017), Maillard (2014)
7.	Biochar	application of biochar	Bai (2019), Liu (2016), Majumder (2019)
8.	Diversification	more or different crops were used in rotation	King (2018), Mathew (2020), McDaniel (2014)
9.	Combined	effect of several practices combined was studied	Aguilera (2013)
10.	High input system	system that aims in increasing carbon by e.g., irrigation, winter crops, etc. according to IPCC (1997)	Ogle (2005)
11.	Set-aside	effect of setting-aside land from crop production and planting trees or grasses	Ogle (2005)





Example of the relationship between the SOC levels in control and effect sizes measured as response ratio or raw mean difference for three studies. Response ratio indicates increasing effect size with decreasing control level. Raw mean difference indicates equal effect sizes for all experiments and does not consider variation in control levels. Triangles indicate an increase or decrease of values; rectangle indicates constant values.