SINGLE-IMPACT FICHE
ORGANIC FARMING SYSTEMS

IMPACT: CARBON SEQUESTRATION

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Note to the reader: This fiche summarises the effects of Organic farming systems on CARBON SEQUESTRATION. It is based on 9 synthesis papers[1], including from 9 to 132 primary studies.

1. WEIGHT OF THE EVIDENCE

CONSISTENCY OF THE IMPACT

The effect of organic farming systems on carbon sequestration (namely soil organic carbon) is reported in **Table 1**.

The table below shows the number of synthesis papers with statistical tests reporting i) a significant difference between the Intervention and the Comparator, that is to say, a significant statistical effect, which can be positive or negative; or ii) a non-statistically significant difference between the Intervention and the Comparator. In addition, we include, if any, the number of synthesis papers reporting relevant results but without statistical test of the effects. Details on the quality assessment of the synthesis papers can be found in the methodology section of this WIKI.

- per unit of area: positive effects were reported for organic systems, with 5 (4 of high quality) synthesis papers for organic cropping systems, 3 for organic systems (as broad category without distiction on different types), 1 for organic livestock products and 1 for organic mixed farming systems. Positive effects are reported for soil organic matter content, soil organic stocks, and soil organic carbon sequestration rate. One meta-analysis reported that, beyond the effects of fertilization intensity, crop residue traits (leaf nitrogen content, leaf dry matter content, fine-root carbon and nitrogen) also play a significant role driving the effects of organic farming on soil organic carbon (SOC) stocks and carbon sequestration rates.
- 1 synthesis paper reported non-significant effect for organic mixed farming systems.
- Another 1 synthesis paper reported negative effect for soil carbon in organic cropping systems managed without net import of organic matter from outside the fields.
- per unit of product: no results were available.

Out of the 9 selected synthesis papers, 8 included studies conducted in Europe (see **Table 2**).

Table 1: Summary of effects. Number of synthesis papers reporting positive, negative or non-statistically significant effects on environmental and climate impacts. The number of synthesis papers reporting relevant results but without statistical test of the effects are also provided. When not all the synthesis papers reporting an effect are of high quality, the number of synthesis papers with a quality score of at least 50% is indicated in parentheses. The reference numbers of the synthesis papers reporting each of the effects are provided in **Table 3**. Some synthesis papers may report effects for more than one impact or more than one effect for the same impact.

				Statistically tested			Non-statistically tested
Impact	Metric	Intervention	Comparator	Significantly positive	Significantly negative	Non-significant	
Increase carbon sequestration	Carbon sequestration per unit of area	Organic cropping systems	Conventional	5 (4)	1	0	1 (0)
		Organic livestock products	Conventional	1	0	0	0
		Organic mixed farming systems	Conventional	1	0	1	0
		Organic systems	Conventional	3	0	0	0

QUALITY OF THE SYNTHESIS PAPERS

The quality of each synthesis paper was assessed based on 16 criteria regarding three main aspects: 1) the literature search strategy and primary studies selection; 2) the statistical analysis conducted; and 3) the evaluation of potential bias. We assessed whether authors addressed and reported these criteria. Then, a quality score was calculated as the percentage of these 16 criteria properly addressed and reported in each synthesis paper. Details on quality criteria can be found in the methodology section of this WIKI.

2. IMPACTS

The main characteristics and results of the 9 synthesis papers are reported in **Table 2** with the terminology used in those papers, while **Table 3** shows the reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**. Comprehensive information about

[1] Synthesis research papers include either meta-analysis or systematic reviews with quantitative results. Details can be found in the methodology section of the WIKI.

the results reported in each synthesis paper, in particular about the modulation of effects by factors related to soil, climate and management practices, are provided in the **summaries of the synthesis papers** available in this WIKI.

Table 2: Main characteristics of the synthesis papers reporting effects on carbon sequestration. The references are ordered chronologically with the most recent publication date first.

Reference number	Population	Scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Ref2	Studies comparing organic crops (Cereals, legumes, vegetables, others) with conventional crops.	Global	132	organic systems with and without biomass transfer	Conventional systems	SOC	These results indicate that organic farming increases SOC only when carbon is transferred between agroecosystems.	88%
Ref7	Previous meta-analyses including studies assessing the performance of organic systems in comparison to conventional systems.	Global	9	Organic systems (annual and perennial crops)	Conventional systems	SOC, C stock (kg /ha)	Higher mean soil carbon content in organic systems than in conventional systems. Similar level of variability.	56%
Ref8	Long-term studies (at least 3 consecutive years) assessing the performance of organic systems in comparison to conventional systems.	Global	101	Organic systems	Conventional systems	Top soil organic carbon stocks, top soil organic carbon sequestration rates and soil respiration.	Organic farming positive effects on soil respiration, SOC stocks, and SOC sequestration rates were significant, even in organic farms with low manure application rates.	94%
Ref14	Long-term studies (minimum 5 years) assessing the performance of organic systems in comparison to conventional systems.	Global	102	Organic systems	Conventional systems	Stock of Organic C in soil (kg m-2)	Organic systems increase soil carbon stock by 8%, compared to conventional systems. However, the result is rated as uncertain, due to the lack of statistical tests.	44%
Ref20	Field-based studies and on-farm research conducted in the continental United States assessing the performance of organic systems in comparison to conventional systems.	Continental USA	55	Organic systems	Conventional systems	Soil organic carbon content	The meta-analysis of studies using shallow sampling methods (0 to 20 cm [0 to 7.8 in]) suggested that organic cropping systems are able to increase SOC relative to that found under conventional monocultures with intensive reliance on external inputs.	44%
Ref21	Field studies (i.e. excluding laboratory and experimental greenhouse studies) conducted under Mediterranean climatic conditions in croplands (including arable crops, orchards and horticulture, but excluding permanent grassland and forests) assessing the performance of organic systems in comparison to conventional systems. In study organic croplands organic practices were applied for at least three consecutive years prior to sampling.	Global (Mediterranean climate)	79	Organic cropping systems	Conventional systems	SOC content and C sequestration rate.	Carbon sequestration is effectively promoted by organic farming practices in Mediterranean cropped soils. This relative increase of SOC sequestration over conventional practices is more marked in intensive cropping systems, where the difference in carbon inputs are higher.	75%
Ref25	Studies assessing the performance of organic systems in comparison to conventional systems. In study organic systems organic practices were applied for at least three consecutive years prior to sampling.	Global	74	Organic systems (all systems, mixed farming systems with zero-input from external)	Nonorganic systems (both conventional and integrated systems)	1) Soil organic carbon concentration; 2) Soil organic carbon stock; 3) Carbon sequestration rate	Metaanalysis of all three effect sizes revealed significantly higher SOC concentrations, SOC stocks, and carbon sequestration rates in soils under organic compared with nonorganic farming management.	75%
Ref27	Field studies, modelling studies and Life Cycle Assessment studies of organic systems in comparison to conventional systems in Europe.	Europe	71	Organic systems	Conventional systems	Soil organic matter per unit of area	The results indicate that organic farming generally leads to significantly higher soil organic matter content, but some conventional farming systems do have the potential to achieve similar or even higher soil organic matter levels when they include the application of manures.	69%
Ref30	Studies assessing the performance of organic systems in comparison to conventional systems.	Global	9	Organic systems	Conventional systems	Organic matter content in soil (%).	Organic matter content in organic plots is significantly higher than in conventional plots.	50%

Table 3: Reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**.

				Statistically tested			Non-statistically tested
Impact	Metric	Intervention	Comparator	Significantly positive	Significantly negative	Non-significant	
Increase carbon sequestration	Carbon sequestration per unit of area	Organic cropping systems	Conventional	Ref2, Ref7, Ref8, Ref20 and Ref21	Ref2		Ref14
		Organic livestock products	Conventional	Ref8			
		Organic mixed farming systems	Conventional	Ref25		Ref25	
		Organic systems	Conventional	Ref25, Ref27 and Ref30			

3. FACTORS INFLUENCING THE EFFECTS ON CARBON SEQUESTRATION

Table 4: List of factors reported to significantly affect the size and/or direction of the effects on carbon sequestration, according to the synthesis papers reviewed.

Factor	Reference number
C input	Ref21
Clay concentrations in soils	Ref25
Climate	Ref8
Crop residues incorporation	Ref30
Crop rotation	Ref25
Crop type	Ref7
External C input	Ref25
External C inputs	Ref25
External N input	Ref25
Fertilisation intensity	Ref8
Input of organic matter	Ref27
Land use type	Ref30
Legume forages	Ref25
Mean annual precipitation	Ref25
Mean annual temperature	Ref25
Organic input	Ref30
Plough depth	Ref30
Presence of leys in the rotation	Ref27
Region (or certification guidelines)	Ref7
Soil disturbance	Ref21

4. KNOWLEDGE GAPS

Table 5: Knowledge gap(s) reported by the authors of the synthesis papers included in this review.

Ref Num	Gap
Ref8	1)Future studies looking at the role of root residue traits for SOC responses to OF; 2) Studies measuring the dynamics of crop residue decomposition in farms subjected to contrasting management practices are particularly needed; 3) Functional traits of cultivars need to be included in future studies addressing the ecosystem-level implications of intraspecific trait variability in agroecosystems; 4) More research is needed to address whether the influence of farming practices on SOC storage is driven by changes in crop litter lability and/or in microbial carbon use efficiency and community composition.
Ref14	1)The depth of sampling varied widely. These differences in sampling depths would influence the results obtained. 2)the bias of the published literature to report outcomes where significant changes are observed, with studies finding no significant differences less likely to be published.
Ref21	According with this analysis of the available data, C input is the main driver of the changes in SOC produced after the adoption of RMPs. However, information on C input was only provided in 42.2% of the data sets studied, and in most cases this information was incomplete. Thus, usually only the amount of C applied in the external C input was provided, while the internal sources of C were ignored.
Ref25	The data mainly cover top soil and temperate zones, whereas only few data from tropical regions and subsoil horizons exist.

5. SYNTHESIS PAPERS INCLUDED IN THE REVIEW

Table 6: List of synthesis papers included in this review. More details can be found in the summaries of the meta-analyses.

Ref Num	Author(s)	Year	Title	Journal	DOI
Ref2	Alvarez, R	2021	Organic farming does not increase soil organic carbon compared to conventional farming if there is no carbon transfer from other agroecosystems. A meta-analysis	Soil Research 60(3) 211-223	10.1071/SR21098
Ref7	Smith, OM; Cohen, AL; Rieser, CJ; Davis, AG; Taylor, JM; Adesanya, AW; Jones, MS; Meier, AR; Reganold, JP; Orpet, RJ; Northfield, TD; Crowder, DW	2019	Organic Farming Provides Reliable Environmental Benefits but Increases Variability in Crop Yields: A Global Meta-Analysis	FRONTIERS IN SUSTAINABLE FOOD SYSTEMS 3	10.3389/fsufs.2019.00082
Ref8	Garcia-Palacios, P; Gattinger, A; Bracht-Jorgensen, H; Brussaard, L; Carvalho, F; Castro, H; Clement, JC; De Deyn, G; D'Hertefeldt, T; Foulquier, A; Hedlund, K; Lavorel, S; Legay, N; Lori, M; Mader, P; Martinez-Garcia, LB; da Silva, P; Muller, A; Nascimento, E; Reis, F; Symanczik, S; Sousa, J; Milla, R.	2018	Crop traits drive soil carbon sequestration under organic farming	Journal of Applied Ecology 30, 1–10.	10.1111/1365-2664.13113

Ref Num	Author(s)	Year	Title	Journal	DOI
Ref14	Kopittke, PM; Dalal RC; Finn D; Menzies NW	2016	Global changes in soil stocks of carbon, nitrogen, phosphorus, and sulphur as influenced by long-term agricultural production.	Global change biology 23, 2509-2519	10.1111/gcb.13513
Ref20	Ugarte, CM; Kwon, H; Andrews, SS; Wander, MM.	2014	A meta-analysis of soil organic matter response to soil management practices: An approach to evaluate conservation indicators	Journal of soil and water conservation 69, 422-430	10.2489/jswc.69.5.422
Ref21	Aguilera, E; Lassaletta, L; Gattinger, A; Gimeno, BS.	2013	Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis	AGRICULTURE ECOSYSTEMS & ENVIRONMENT 168, 25-36.	10.1016/j.agee.2013.02.003
Ref25	Gattinger A; Muller A; Haeni M; Skinner C; Fliessbach A; Buchmann N; Mäder P; Stolze M; Smith P; El-Hage Scialabba N; Niggli U.	2012	Enhanced top soil carbon stocks under organic farming	PNAS 109 (44), 18226-18231.	10.1073/pnas.1209429109
Ref27	Tuomisto HL; Hodge ID; Riordana P; Macdonald DW	2012	Does organic farming reduce environmental impacts? – A meta-analysis of European research	Journal of Environmental Management 112, 309-320	10.1016/j.jenvman.2012.08.018
Ref30	Mondelaers, K; Aertsens, J; Van Huylenbroeck, G.	2009	A meta-analysis of the differences in environmental impacts between organic and conventional farming	BRITISH FOOD JOURNAL 111 10, 1098-1119	10.1108/00070700910992925