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What are the effects of agricultural management on soil organic carbon (SOC) stocks?

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Abstract

Background: Changes in soil organic carbon (SOC) stocks significantly influence the atmospheric C concentration. Agricultural management practices that increase SOC stocks thus may have profound effects on climate mitigation. Additional benefits include higher soil fertility since increased SOC stocks improve the physical and biological properties of the soil. Intensification of agriculture and land-use change from grasslands to croplands are generally known to deplete SOC stocks. The depletion is exacerbated through agricultural practices with low return of organic material and various mechanisms, such as oxidation/mineralization, leaching and erosion. However, a systematic review comparing the efficacy of different agricultural management practices to increase SOC stocks has not yet been produced. Since there are diverging views on this matter, a systematic review would be timely for framing policies not only nationally in Sweden, but also internationally, for promoting long-term sustainable management of soils and mitigating climate change.

Methods: The systematic review will examine how changes in SOC are affected by a range of soil-management practices relating to tillage management, addition of crop residues, manure or other organic "wastes", and different crop rotation schemes. Within the warm temperate and the snow climate zones, agricultural management systems in which wheat, barley, rye, oats, silage maize or oilseed rape can grow in the crop rotation will be selected. The review will exclusively focus on studies conducted over at least 10 years. Searches will be made in 15 publication databases as well as in specialist databases. Articles found will be screened using inclusion/exclusion criteria at title, abstract and full-text levels, and screening consistency will be evaluated using Kappa tests. Data from articles that remain after critical appraisal will be extracted using a predefined spreadsheet. Subgroup analyses will be undertaken to elucidate statistical relationships that are specific to particular type of management interventions. Meta-regression within subgroups will be performed as well as sensitivity analysis to investigate the impact of removing groups of studies with low or unclear quality.

Keywords: Soil organic carbon, Agricultural practices, Long-term, Tillage, Fertilization, Crop rotation, Cover crop, Sequestration

Background

The largest global stock of organic carbon (C) on land is contained in soils (2500 Pg of C to 2-m depth) and is about twice as large as the atmospheric C stock [1-3]. Changes in soil C stocks may thus significantly influence the atmospheric carbon dioxide (CO_2) concentration. Since approximately 12% of the soil C stock is present in cultivated soil [3] and agricultural soils occupy about 35% of the global land surface [4], soil management is potentially a powerful tool for climate change mitigation through C sequestration [5,6]. Additional benefits from increasing C stocks in agricultural soils are increased soil fertility [7,8] and improved physical and biological properties of the soil [9] by reduced bulk density, increased water-holding capacity, improved soil structure and enhanced microbial activity [10].

It is important to acknowledge that an increase in the soil C stock does not imply a decrease in the atmospheric C stock by the same amount, since the management employed to achieve increased stocks of soil organic carbon (hereafter denoted as SOC) may themselves be using

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non-renewable energy and cause changes in the atmospheric C stock [3,8]. To feed a growing world population, converting land from annual cropping to, for example, forest or grassland may require conversion of land in the opposite direction elsewhere [11]. The net effect of a certain land-use change or soil management practice on atmospheric CO_2 needs thus to be considered in a broader context [12].

Guo and Gifford [13] performed a meta-analysis of data from 74 publications indicating that soil C stocks decline after land-use changes from pasture to plantation (-10%), native forest to plantation forest (-13%), native forest to cropland (-42%), and pasture to cropland (-59%). They also found that soil C stocks increase after land-use changes from native forest to pasture (+8%), cropland to pasture (+19%), cropland to plantation forest (+18%), and cropland to secondary forest (+53%). The results varied, however, depending on factors such as annual precipitation, plant species and, not least, length of study periods.

It is quite evident that pastures and forests, whether native or plantation, compared to cropland, are more efficient in storing C in the soil. In Sweden, it has been calculated that nationwide the 270 Tg C stock in agricultural surface soil (0–25 cm) is actually decreasing at a rate of 1 Tg year^{-1} [14]. The loss of C from agricultural soils on a global scale has been a matter of considerable debate, but according to Lal [15] the C flux from soil to the atmosphere is estimated to be 0.8–1.2 Pg C year^{-1}, whereas C flux from soil to the ocean is 0.6 Pg C year^{-1}.

Even though organic C in many agricultural soils is being depleted through various mechanisms (oxidation/mineralization, leaching and erosion), there are measures other than land-use changes that potentially can slow down or reverse this trend. Such measures include: i) diverse crop rotations including, for example, leys and cover crops, ii) organic amendments such as manure or crop residues, and iii) tillage modifications such as minimum or no tillage.

Previous studies

The literature on carbon sequestration in agricultural soils is extensive. However, SOC responds slowly to changes in agricultural management [16]. Most SOC changes require many years to be detectable by present analytical methods [17], and therefore long-term experiments are required. Nevertheless, a substantial number of studies have been performed and few reviews have been published recently [6,13,15,18,19].

Gonzalez-Sanchez et al. [6] concluded from a meta-analysis of data of 29 publications (from Spain) that some forms of conservation agriculture (i.e., no tillage and implementing cover crops) can have positive effects on SOC. Govaerts et al. [18] reviewed three aspects of conservation agriculture: reduction in tillage, retention of crop residues and use of crop rotations. The data (mainly from the Americas) indicated that the largest contribution of conservation agriculture to reducing emissions from farming activities is from the reduction of tillage operations.

Soilservice [19] reviewed the soil organic matter (SOM) content, which is closely linked to SOC, in conventional and organic farming, respectively. The conventional farming areas included management regimes with mineral fertilizer and/or pesticide application, whereas organic fields included management types with organic fertilizer and no pesticides. For the period 1945–2009 they found 29 studies meeting their screening criteria for meta-analysis. The results indicated a positive effect of organic fertilizers and/or no pesticides on SOM content (Figure 1).

Identification of topic and stakeholders

The environmental benefits of increasing SOC stocks in cropland are mainly related to climate change mitigation, agricultural sustainability and land-use issues (by enhancing the productivity of the soil less land is needed to produce a certain amount of food and fiber). The topic was suggested by Karin Hjerpe at the Swedish Board of Agriculture (May 4, 2012 and September 20, 2012). At the general stakeholder meeting arranged by Mistra EviEM (September 24, 2012), the suggestion was put forward again by Olof Johansson at the Swedish

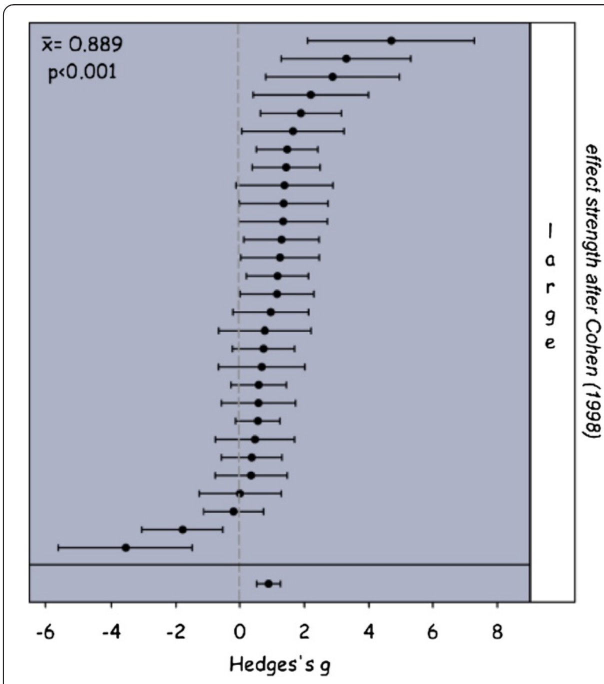

Figure 1 Forest plot of the effect sizes (Hedges' g) of 29 studies on the effect of conventional *vs*. organic farming on SOM. From Soilservice [19].

Board of Agriculture. The Swedish Board of Agriculture is responsible for the national environmental quality objective "A varied agricultural landscape". One expected outcome within this goal is that arable land will have a well-balanced nutrient status, good soil structure and humus content. Another expected outcome is that the land will be cultivated in such a way as to sustain the long-term productivity of the soil. These outcomes are closely related to SOC. The Swedish Board of Agriculture is also involved in issues regarding climate change. The agency has been commissioned by the government to work out an action plan aimed at reducing greenhouse gas emissions from Swedish agriculture. In their reports [20,21] it was concluded that while there is a large potential for C sequestration in soils globally, it is not clear how significant it is for measures that can be applied in Sweden and in Swedish climatic conditions.

The Swedish Environmental Protection Agency (EPA) is another user of the suggested review. The Swedish EPA is responsible for the environmental quality objective "Reduced Climate Impact". In this context, the Swedish Parliament has adopted a vision of zero net emissions of greenhouse gases to the atmosphere in Sweden by 2050.

The review is also of interest for the Federation of Swedish Farmers (LRF), which is interested in both the environmental issues and the productivity aspect. In their Climate Policy it is stated that increased SOM content in cropland potentially can reduce concentrations of greenhouse gases in the atmosphere and that such opportunities should be seized. The Federation of Swedish Farmers is also taking part in Focus on Nutrients ("Greppa Näringen" in Swedish), which is a joint venture between LRF, the Swedish Board of Agriculture, the County Administrative Boards and a number of companies in the farming sector. Focus on Nutrients offers advice to farmers on, e.g., climatic issues and SOC management.

The systematic review question is scientifically relevant and has received considerable research interest. Although several meta-analyses and literature reviews have been published for example [6,13,15], a systematic review comparing the efficacy of different management techniques to increase SOC stocks in agricultural areas has not yet been produced. Since there are diverging views on this matter, a systematic review would be timely. Thus, both the primary user of the review (the Swedish Board of Agriculture) and scientists from the Swedish University of Agricultural Sciences endorsed the idea of a systematic review on this topic should be conducted.

During a stakeholder meeting at the EviEM secretariat (June 4, 2013), representatives from the Swedish Board of Agriculture, Swedish Environmental Protection Agency, Federation of Swedish Farmers, and Swedish University of Agricultural Sciences discussed the formulation of the review question and exclusion/inclusion criteria. It was suggested that the focus should be on long-term studies of how agricultural management affect SOC stocks within the temperate climate zone (humid and summer dry) as well as the snow climate zone (northern Sweden). The stakeholders put forward that cereal grains such as wheat and barley were of particular interest, but also other crops that could become more important in Sweden in a changing climate (such as maize). All agricultural management types and soil types within these agricultural regions were of interest. Greenhouse gases other than CO_2, such as methane (CH_4) and nitrous oxide (N_2O), and studies solely focusing on soil phosphorus and nitrogen were considered to be outside the systematic review's scope. There is a lack of data on CH_4 since it is not often measured in upland soils. Similarly, there are few data on long-term changes in N_2O in which contrasting treatments have reached a new equilibrium. It is therefore difficult to integrate short-term N_2O processes with long-term trends in SOC changes. Stakeholders also underlined, that although the review question by definition must be fairly narrow, the narrative synthesis should attempt to have a systemic approach. For example, SOC may increase under bioenergy crops, but if the total cropped area is the same, less food will be produced. Certain interventions may also require increased use of non-renewable energy leading to a reduced net effect on carbon emissions.

Objective of the review

The effect of land-use change on SOC stocks has been documented in many parts of the world. However, more pertinent to the systematic review suggested here is that there also are a fair number of studies on the effects of various soil management practices within a given type of land-use, e.g., cropland, on SOC stocks. In order to enable a quantitative evaluation, or a meta-analysis, the various soil management practices should be well defined and, if possible, treated separately. These include i) diverse crop rotations with winter cover crops and leys, ii) organic amendments such as manure or crop residues, iii) tillage modifications such as minimum or no tillage.

Primary question: What are the effects of agricultural management on soil organic carbon (SOC) stocks?

Components of the primary question:

Population: Arable soils in agricultural regions from the warm temperate climate zone and the snow climate zone (according to the Köppen-Geiger climate classification; see *Relevant subjects* below).

Within these climate zones, agricultural management systems in which wheat, barley, rye, oats, silage maize or oilseed rape *can* grow in the crop rotation will be selected.

Intervention: A range of soil management practices relating to tillage management, addition of crop residues, manure or other organic "wastes", and different crop rotation schemes.

Comparator: Different or no intervention.

Outcome: Changes of SOC stocks, measured as a relative rate of change per year.

Methods

Searches

A review scoping exercise was conducted to test alternative search strings. The exercise resulted in the selection of the following search terms:

Population: soil*

Population: arable, agricult*, farm*, crop*, cultivat*

Intervention: till*, "direct drill*", fertili*, bio*solid*, organic, manur*, sewage, compost*, amendment*, biochar*, digestate*, crop residue*, crop straw*, mulch*, crop rotat*, break crop*, (grass OR clover) ley*, legume*, bioenergy crop*, cover crop*, "grass clover", "crop* system*", winter crop* , spring crop*, summer fallow*, "catch-crop*", intercrop*, conservation

Outcome: "soil organic carbon", "soil carbon", "soil C", "soil organic C", SOC, "carbon pool", "carbon stock", "carbon storage", "soil organic matter", SOM, "carbon sequestrat*", "C sequestrat*"

The terms within each of the categories 'population', 'intervention', and 'outcome' will be combined using the Boolean operator 'OR'. The four categories will then be combined using the Boolean operator 'AND'. An asterisk (*) is a 'wildcard' that represents any group of characters, including no character. The use of Boolean operators and truncation will be modified according to the idiosyncrasies of each publication database and how this is done will be documented.

The following search strings will be used:

English: soil* AND (arable OR agricult* OR farm* OR crop* OR cultivat*) AND (till* OR "direct drill*" OR fertili* OR bio*solid* OR organic OR manur* OR sewage OR compost* OR amendment* OR biochar* OR digestate* OR crop residue* OR crop straw* OR mulch* OR crop rotat* OR break crop* OR (grass OR clover) ley* OR legume* OR bioenergy crop* OR cover crop* OR "grass clover" OR "crop* system*" OR winter crop* OR spring crop* OR summer fallow* OR "catch-crop*" OR intercrop* OR conservation) AND ("soil organic carbon" OR "soil carbon" OR "soil C" OR "soil organic C" OR SOC OR "carbon pool" OR "carbon stock" OR "carbon storage" OR "soil organic matter" OR SOM OR "carbon sequestrat*" OR "C sequestrat*")

In addition to data in the scientific literature it is anticipated that data will be found also in the grey literature. Such data will be searched for using search engines and specialist websites using the simplified search terms given below. In each case, the first 100 hits based on relevance will be examined for appropriate data. No particular time or document type constraints will be applied. In addition, a search in Google Scholar based on title words only (advanced search) will also be made since partly different articles may be found.

English: (carbon AND sequestration AND soil AND agriculture)

Swedish: (kol AND lagring AND mark AND jordbruk)

Danish: (kulstof AND indhold AND jord AND landbrug)

French: (carbone AND stockage AND terre AND agriculture)

German: (kohlenstoff AND lagerung AND boden AND landwirt)

Italian: (carbonio AND stoccaggio AND suolo AND agricoltura)

Number of hits using the above search strings in Google Scholar on August 29, 2013 (Google Scholar based on title words only on December 9, 2013): English 65 400 (52), Swedish 1050 (0), Danish 1770 (0), French 15 190 (0), German 3550 (0), Italian 1630(0)).

Estimating the comprehensiveness of the search

The final search string resulted in 10 328 hits in Web of Knowledge and found 22 of 23 "reference articles" selected a priori as highly relevant. The only remaining reference article was a narrative review on the value of long-term experiments [17].

Bibliographies in review articles will be searched for relevant primary studies as a measure of the comprehensiveness of the search strategy. We will include relevant references in review articles previously missed by our search strategy. By using a large number of generic intervention terms and possible variations of the outcome term, our search strategy will be of a high-sensitivity and low-specificity type. This was demonstrated by the relatively small reduction in the number of articles after excluding 'particulate organic matter' and 'POM' as well as 'nitrogen' and 'N'. The specificity was judged to be too low when including 'carbon', and this outcome term was thus removed from the search string (leading to reduction from 15 649 to 9364 articles). The final number of articles after including all publication databases is expected to increase by a factor of two compared to the Web of Knowledge search.

Publication databases

The search aims to include the following online databases:

- Academic Search Premier
- Agricola
- AGRIS: Agricultural database (FAO)
- Biological Abstracts
- BioOne
- Directory of Open Access Journals

- Food Science and Technology Abstracts
- Georef and Geobase
- IngentaConnect
- JSTOR
- PubMed Central
- Scopus
- SwePub
- Web of Science
- Wiley Online Library

Internet searches

- Google (www.google.com)
- Google Scholar (scholar.google.com)
- Dogpile (www.dogpile.com)
- Scirus (www.scirus.com)

Specialist searches for grey literature

- *Aarhus University, Department of Agroecology* (http://www.au.dk/en/, http://agro.au.dk/en/)
- *African Network for Soil Biology and Fertility* (http://agra.ciat.cgiar.org/)
- *Columbia Basin Agricultural Research Center* (http://cbarc.aes.oregonstate.edu/long_term_pubs)
- *European Environment Agency* (http://www.eea.europa.eu/)
- *European Soil Portal* (http://eusoils.jrc.ec.europa.eu)
- *Eusomnet* (http://www.ufz.de/somnet)
- *GCTE SOMNET* (http://gcmd.nasa.gov/KeywordSearch/Keywords.do?Portal=GCMD_legacy&KeywordPath=Parameters|AGRICULTURE|SOILS|CARBON&MetadataType=0&lbnode=mdlb2)
- *GRACEnet, USDA Agricultural Research Service* http://www.ars.usda.gov/research/programs/programs.htm?np_code=212&docid=21223
- *Indian Agricultural Statistics Research Institute* (http://iasri.res.in/)
- *National Soil Carbon Network (NSCN) of the US Forest Service* (http://www.nrs.fs.fed.us/niacs/carbon/nscn/)
- *Rapid Assessment of US Soil Carbon (RaCA), USDA Natural Resource Conservation Service* (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054164)
- *Rothamsted Research* (http://www.rothamsted.ac.uk/)
- *Soil Carbon Center at Kansas State University* (http://soilcarboncenter.k-state.edu/)
- *Soilservice* (http://www4.lu.se/o.o.i.s/26761)
- *Swedish Board of Agriculture* (http://www.jordbruksverket.se)
- *Swedish Environmental Protection Agency* (http://www.naturvardsverket.se)
- *Swedish University of Agricultural Sciences* (http://www.slu.se)
- *UC Davis, Agricultural Sustainability Institute* (http://ltras.ucdavis.edu/)
- *University of Copenhagen* http://www.ku.dk/english
- *University of Illinois, Department of Crop Sciences* (http://cropsci.illinois.edu/research/morrow)
- *USDA Agricultural Research Service* (http://www.ars.usda.gov/research/programs/programs.htm?np_code=211&docid=22480)
- *Victorian Long Term Agro-ecological Experiments* (http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_ltae)
- *Videncentret for Landbrug* (http://www.vfl.dk/English/NyEnglishsite.htm)
- *Working Group for Long-term Experiments (LTE)* (http://www.isofar.org/sections/wg-long-term-experiments.html)
- *World Bank* (www.worldbank.org/reference/)

Supplementary searches

It is anticipated that there will be a number of unpublished data sets containing information from long-term experiments. Several of the authors in the review team will search for such data sets within their respective organizations (including some of the specialist websites mentioned above).

Study inclusion/exclusion criteria

Articles found by searches in databases will be evaluated for inclusion at three successive levels. First they will be assessed by title, then by abstract, and finally by studying the full text. In cases of uncertainty, the reviewer will tend towards inclusion at all levels. One reviewer will perform the screening of all retrieved articles at the title and abstract level. To check that the screening is consistent and complies with the agreed inclusion/exclusion criteria, a subset of at least 200 articles will be screened by two reviewers at both the title and abstract levels. Kappa tests will be used to evaluate screening consistency. If Kappa tests indicate that the reviewers are inconsistent in their assessment ($K < 0.6$), discrepancies will be discussed and the inclusion/exclusion criteria will be clarified or modified. Next, each article found to be relevant on the basis of title and abstract will be judged for inclusion by reviewers studying the full text. Each reviewer will receive an approximately equal number of articles. Before screening full text, a subset of at least 100 articles will be double-screened and Kappa tests will be used to test consistency between reviewers.

Each study must pass each of the following criteria in order to be included at any of the three screening stages:

Relevant subject(s): Arable soils in agricultural regions. Regional factors are likely to be of much less importance than the type of management. Following the Köppen-Geiger climate classification [22] (Figure 2), we will include agricultural regions from the warm temperate climate zone (fully humid and summer dry, i.e., Cfa, Cfb, Cfc, Csa, Csb, Csc) and the snow climate zone (fully humid, i.e., Dfa, Dfb, Dfc). Within these climate zones, agricultural management systems in which wheat, barley, rye, oats, silage maize or oilseed rape *can* grow in the crop rotation will be selected. Leys and bioenergy crops may occur as part of the crop rotation, but permanent grasslands, paddy rice systems, agroforestry systems and orchards will not be included. There will be one restriction on soil type, organic soils, since management rather leads to subsidence than to changes in SOC concentration [23]. Given the global scope of this systematic review we anticipate that a very large number of articles will be included after screening for relevance. At the abstract screening stage, we will therefore categorize studies as either belonging to the northern hemisphere or the southern hemisphere. Studies from the northern hemisphere will be prioritized if time and resource constraints prevent us from including all articles.

Relevant types of study design: The practices or systems under study must have been in operation for 10 years or more, as it is almost impossible to detect significant changes in SOC in shorter time periods (see [24]). The changes from one year to another are so small so that the change in SOC will be less than spatial variation within a field. Relevant types of studies include not only comparisons between specific agricultural practices at individual sites but also comparisons between multiple types of management factors alone or combined. Studies of how agricultural practices have affected SOC stocks at a single site over time will only be included if there is more than one treatment, as local variation in SOC can be high and information from single treatments (e.g. between farms or regions) are not possible to evaluate.

Relevant intervention(s): Any type of agricultural management that could change SOC stocks, including cropping systems that have ley, legumes or bioenergy plants in the rotation. Experimental treatments may include a range of different soil management practices introduced at the onset of the experiment, for example, different tillage practices, fertilization schemes, and cover/catch crops. Studies of biochar will also be included in the systematic review. As long as relevant data are found in the articles they will be included regardless of study purpose (e.g. C sequestration to counteract climate change or management intended to increase soil fertility). Multiple interventions without information on specific management/

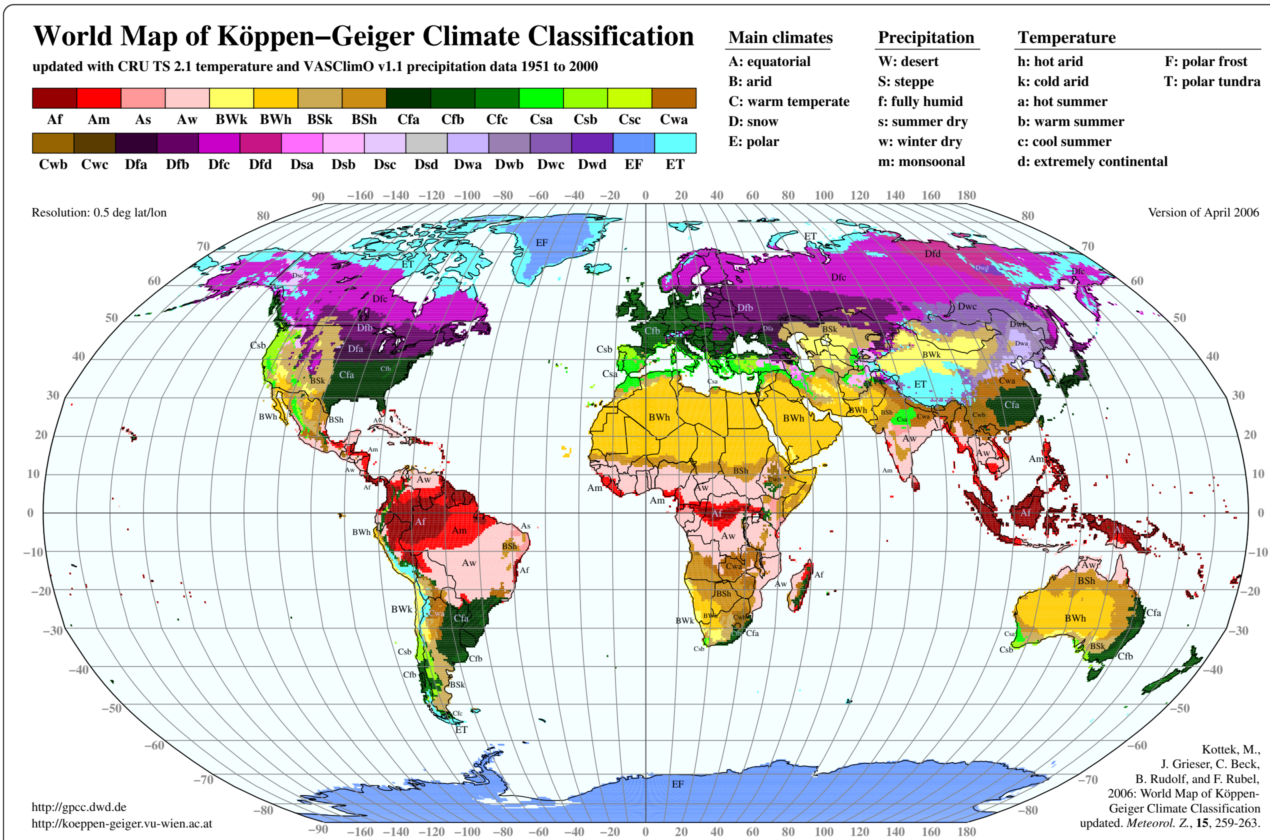

Figure 2 World map of Köppen-Geiger Climate Classification. From Kottek et al. [22].

treatments made in the same crop field preclude the opportunity to assess the effect of each intervention separately. For example, comparisons of organic and conventional farming may not always separate between different crop field treatments and such studies will then be rejected on the basis of study quality.

Relevant comparator(s): In studies of specific types of interventions, the relevant comparator is a treatment where no such intervention has occurred, or where it has been applied at a different level. In studies of entire agricultural systems, 'current' or 'conventional' farming practices that encompass a suite of management practices may be a relevant comparator as long as differences in all management factors are provided.

Relevant outcome(s): Relative changes of SOC will be the main focus. The C stock can be given as Soil Organic Carbon (SOC), Total Organic Carbon (TOC), Total Carbon (TC) or Soil Organic Matter (SOM), and it can be measured as mass and/or concentration.

Potential effect modifiers and reasons for heterogeneity

The following potential effect modifiers (non-intervention variables that might influence the outcome) will be considered and recorded in the review:

- Type of crop
- Type of crop rotation
- Soil type, mineral soil texture class
- Amount/type of fertilizers
- Latitude and longitude
- Climate (average annual precipitation and average annual temperature)
- Topography (altitude, slope)
- Previous land-use

The above list was compiled by the review team after consultation with stakeholders and external experts. Further modifiers and causes of heterogeneity will be identified and defined in an iterative process.

Study quality assessment

Studies still included after full text screening will be subject to quality assessment. During this process the studies will be categorized into one of the categories: a) do not meet quality criteria, b) acceptable study quality, and c) high study quality. Studies that do not meet the quality criteria will be excluded from data synthesis, whereas studies of acceptable and high quality will be retained. Assessment of study quality will be based on:

- Level of replication
- Method of sample selection (randomization)
- Paired, blocked or nested designs to avoid spatial effects
- Experimental duration
- Sampling frequency
- Soil sampling method (surface soil versus subsoil)
- To what extent potential effect modifiers have been assessed

Ideally, studies should sample both surface soil and subsoil. Studies sampling only surface soil may be biased and lead to misinterpretation of intervention effects, since the SOC concentration may increase with soil depth depending on the treatment applied [25]. Changes in SOC stock may go along with changes in bulk density [26]. Ideally, SOC would thus be measured not only by volume but also by soil mass. In most cases, however, SOC is measured as concentration rather than mass.

When assessing study quality the articles will be evenly distributed among the reviewers. A subset of at least 25% of studies will be appraised by a second reviewer. Conclusions will be compared, and where reviewers differ, discrepancies will be discussed and reconciled individually. A study may be included even if not all criteria have been fulfilled. Detailed reasoning will be recorded in a transparent manner. A list of studies rejected on the basis of quality assessment (i.e., do not meet quality criteria) will be provided in an appendix to the review together with the reasons for exclusion.

Data extraction strategy

All authors in the review team will participate in extracting metadata (effect modifiers such as types of crop, crop rotation, soil etc.). To make data extraction as consistent as possible, metadata will be entered into a spreadsheet with predefined categories. In case it is not possible to assign metadata to a specific category, it will be assigned to 'Other, please specify' (to allow the use of further categories if needed). One reviewer will be solely responsible for extracting numerical data from main text, tables and graphs. Data extraction will be double-screened for a subset of articles to check for consistency. The image analysis software WebPlotDigitizer will be used to extract data from graphs. To enable comparison between different interventions when measured at different sites, change in SOC will be recorded as the relative rate of change per year.

Data synthesis and presentation

A narrative synthesis of data from all studies with weighting as 'acceptable' or of 'high quality' will describe the quality of the results along with the findings. Tables will be produced to summarize the results. Precise details of the quantitative analysis will only be known when full texts have been assessed for their contents and quality.

Subgroup analyses will be undertaken to elucidate statistical relationships that are specific to particular type of management interventions. Overall effects of different management effects on SOC will be presented visually in forest plots. Separate analyses of surface soil and subsoil rates of SOC change will be undertaken for studies reporting both measures. Meta-regression within subgroups will be performed using rates of SOC change as a response variable and the effect modifiers as explanatory variables. Finally, we will perform sensitivity analysis to investigate the impact of removing studies with acceptable study quality.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
This review protocol is based on a draft written by BS. The draft was discussed with all authors at a meeting on 15-16 August, 2013. All authors participated in the drafting, revision and approval of the manuscript.

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