**Systematic Review Protocol**

**Title**
Are greenhouse gas fluxes lower from ley or perennial fallow than from arable organic soils? A systematic review protocol

**Citation:**
Alena Holzknecht , Örjan Berglund, Magnus Land, Jacynthe Dessureault-Rompré, Lars Elsgaard, Kristiina Lång. Are greenhouse gas fluxes lower from ley or perennial fallow than from arable organic soils? A systematic review protocol: a Systematic Review Protocol. PROCEED-23-00143 Available from:
https://proceedevidence.info/protocol/view-result?id=143
https://doi.org/10.57808/proceed.2023.13

**Corresponding author's email address**
magnus.land@formas.se

**Keywords**
Gas fluxes, climate change, land-use, peat soils, policy

**Background**
Cultivated peatlands are widespread in temperate and boreal climate zones. For example, in Europe about 15% of the pristine peatland area have been lost through drainage for agricultural use. When drained, these organic soils are a significant source of greenhouse gas (GHG) emissions. To reach climate goals, the agricultural sector must reduce its GHG emissions, and one measure that has been discussed is changing land use from cropland to ley production or perennial green fallow. This management change leads to lower reported emissions, at least when using the IPCC default emission factors (EF) for croplands and grasslands on organic soils (IPCC 2014). However, there was a limited background dataset available for developing the EFs, and other variables than management affect the comparison of the land use options when the data originates from varying sites and years. Thus, the implications for future policies remain uncertain. This protocol describes the methodology to conduct a systematic review to answer the question of whether ley production or perennial green fallow can be suggested as a valid alternative to annual cropping to decrease GHG emissions on organic soils in temperate and boreal climate.

**Theory of change or causal model**
Microbial processes control GHG emissions with oxygen availability as a main driver, which is itself restricted by soil water content. However, further drivers of GHG emissions relate to soil physical properties, organic matter content, and access to nutrients. For example, it is a combination of nitrogen fertilisation, plant nitrogen uptake and the conditions for anaerobic environments to form, which determine to what extent the soil becomes a source of nitrous oxide. These factors will be influenced by the land use and management methods that are applied at farm level [1, 2].

**Stakeholder engagement**
The Swedish Board of Agriculture has expressed a need for a systematic review of existing research results to find out what evidence there is to justify the suggested interventions. A stakeholder group (representatives from farmers, advisory board, regional government, farmers union and the Swedish Board of Agriculture) were invited to a meeting at an early stage in the planning of the forthcoming systematic review, where they were asked to share their thoughts and ideas about the systematic

review. However, the stakeholders have not been further involved in writing the protocol.

**Objectives and review question**
The question attempted to be answered in the forthcoming systematic review is: ”What is the effect of ley or perennial green fallow on the flux of greenhouse gases from agricultural organic soils?”

**Definitions of the question components**
• Population: Organic soils on agricultural land in temperate and boreal climate zones. Such organic soils are often drained peatland, but other origins may occur. • Intervention: Using land for grazed or ungrazed, permanent or cultivated grassland (ley) or setting land aside from agricultural production (perennial green fallow) without attempt to raise the groundwater level. Rewetted grasslands are thus not included. Growing woody energy crops is not an eligible intervention or comparator. Growing grass-like energy crops is an eligible intervention. • Comparator: Using land for various crop rotations involving annual crops. Land uses may be categorised regarding tillage, fertilisation, and other management practices. • Outcome: Flux of CO2, N2O, or CH4.

**Search strategy**
The searches in bibliographic databases will be conducted using English search terms, including articles in other languages with English titles and abstracts. The search string comprises three substrings related to the population, intervention, and outcome, respectively (see below). The substrings will be combined with the Boolean operator AND. The format of the search strings will be adapted to each database (see 8.1). There will be no restrictions regarding publication dates or publication types. The search substrings are: 1. "organic soil" OR "organic soils" OR peat* OR histosol* OR "muck sediment" OR "muck sediments" OR "muck soil" OR "muck soils" OR gyttja OR moorsh* OR wetland* OR turf* OR coprogenous OR muskeg OR suo OR mud OR muds OR swamp OR swamps OR lowland* OR fen OR fens OR mire OR mires OR marsh* OR morass OR quag* OR gley* OR "carbon rich" OR "black soil" OR "black soils" OR bog* OR "high organic carbon" OR hydromorphic 2. grass OR grassland* OR ley* OR fallow OR pasture OR forage OR perennial* OR mesocosm* OR lysimeter* OR semifield* OR legume* OR pulse* OR alfalfa* OR lupin* OR bean* OR lentil* OR clover* OR meadow* OR timothy OR set-aside OR setaside OR pea OR peas OR crop* OR graz* 3. "greenhouse gas" OR "greenhouse gases" OR "carbon dioxide" OR CO2* OR "carbon emission" OR "carbon emissions" OR "nitrous oxide" OR "nitrous oxides" OR N2O OR "laughing gas" OR methane OR CH4 OR "global warming potential" OR GHG* OR "net ecosystem exchange" OR "net ecosystem production" OR respiration OR "carbon balance" OR "trace gas" OR "trace gases" OR NEE OR NEP OR "carbon turnover" OR "eddy covariance" OR "dinitrogen oxide" OR "dinitrogen monoxide" OR "marsh gas"

**Bibliographic databases**
Bibliographic databases (search field shown within parentheses) include Scopus (title, abstract and keywords), Web of Science Core Collection (topic), CAB Abstracts (topic), ProQuest Natural Science Collection (abstract and summary text), and Directory of Open Access Journals (all fields). The Web of Science Core Collection include Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Emerging Sources Citation Index, Conference Proceedings Citation Index – Science, Conference Proceedings Citation Index - Social Sciences & Humanities. The ProQuest Natural Science Collection include AGRICOLA, Agricultural Science database, Environmental Science database, Environmental Science index, Biological Science database, Biological Science index, Earth, atmosphere & Aquatic Science database. To capture grey literature the following databases will be searched: BASE (search terms in English, German, French, and Danish), Swepub (search terms in Swedish and English), Finna (search terms in Finnish and English), and ProQuest Theses and Dissertations (search terms in English).

**Web-based search engines**
We will use Google Scholar through Publish or Perish [3] using the search strings shown below. The first 300 search results for each search string using search terms in English will be screened for relevance, whereas the first 200 search results using search terms in Danish, Finnish, German, and Swedish will be screened. 1) cultivated AND peat AND ("greenhouse gas" OR "greenhouse gases" OR "carbon dioxide" OR CO2 OR "nitrous oxide" OR N2O OR methane OR CH4) 2) arable AND peat AND ("greenhouse gas" OR "greenhouse gases" OR "carbon dioxide" OR CO2 OR "nitrous oxide" OR N2O OR methane OR CH4) 3) crop AND peat AND ("greenhouse gas" OR "greenhouse gases" OR "carbon dioxide" OR CO2 OR "nitrous oxide" OR N2O OR methane OR CH4) 4) cultivated AND "organic soil" AND ("greenhouse gas" OR "greenhouse gases" OR "carbon dioxide" OR CO2 OR "nitrous oxide" OR N2O OR methane OR CH4) 5) arable AND "organic soil" AND ("greenhouse gas" OR "greenhouse gases" OR "carbon dioxide" OR CO2 OR "nitrous oxide" OR N2O OR methane OR CH4) 6) crop AND "organic soil" AND ("greenhouse gas" OR "greenhouse gases" OR "carbon dioxide" OR CO2 OR "nitrous oxide" OR N2O OR methane OR CH4)

**Organisational websites**
We will search specialist websites, such as environmental protection agencies or boards of agriculture in countries relevant for the review as defined in the PICO. The websites will be identified in collaboration with stakeholders during the review process and reported in the systematic review.

**Comprehensiveness of the search**
The comprehensiveness of the search was tested through a list of benchmark articles that the protocol development team identified as relevant for answering the systematic review question. All but one of the articles indexed in at least one of the searched bibliographic databases were captured by the search strings used. The one missing article [3], in Danish, has a short English abstract with little information. Although relevant to the review question, it does not conform with our inclusion criteria on the outcome. Therefore, we have not judged it meaningful to adjust the search string any further to capture this article. The searches using Google Scholar with search strings in English capture all benchmark publications classified as grey literature except one thesis [4]. However, when searching for this publication using the title as the search string, we find at least one web page with this publication and all the words in our Google Scholar search strings. It should thus have been picked up by the searches, but for some reason it was not ranked among the top 300 search results. We judge it unfeasible to adjust the search strategy any further, but it is still possible that this publication will be captured by the searches using search terms in German.

**Search update**
In case the systematic review will get published more than 18 months after the searches, the searches in bibliographic databases will be updated. If the systematic review will be published earlier, search updates will depend on available resources after an assessment of the importance of a search update.

**Screening strategy**
Duplicates will be identified and removed using EndNote 20. Unique articles will then be uploaded to the EPPI Reviewer Web software where the screening will be performed at two stages. At stage 1 the titles and abstracts will be screened and at stage 2 the full texts will be screened. All review team members will be involved in consistency testing. However, once the eligibility criteria are judged to be clear and consistently applied, the bulk of the search results will be screened by two reviewers.

**Eligibility criteria**

Eligible population: Articles must include organic soils on agricultural land in climate zones Cfb, Dfa, Dfb, or Dfc according to the Köppen climate classification [5]. As definitions of organic soils vary [6], there will be two categories: “true” peat soils defined as Histosols [7] or having an organic carbon (OC) content >12% and peat depth >30 cm, and shallow and/or lower organic carbon peat soils with >5% OC and >10 cm depth. Eligible intervention: Articles must include grazed or ungrazed, permanent or cultivated grassland (ley) or land set aside from agricultural production (perennial green fallow). Ley must be continuous, i.e. without tillage for at least three years. Growing woody energy crops is not an eligible intervention. Growing grass-like energy crops is an eligible intervention, as such may have similar characteristics as other grassland species. Eligible comparator: Various crop rotations involving annual crops. Eligible outcome: Flux of CO2, N2O, CH4, or several of those. Gas fluxes must have been measured directly using, for example, dark or transparent chambers, eddy covariance measurements, or concentration gradient methods. Indirect measures, such as soil subsidence or changes in soil organic carbon stocks, are not eligible. Eligible study designs: We expect that most studies will have a Control-Impact (CI) study design, but we will also include Before-After (BA) or a Before-After Control-Impact (BACI) study designs. Mesocosm studies are eligible, but the mesocosms should be dimensioned large enough (larger than approximately 0.5 m2) and contain soil sufficiently undisturbed to mimic a full-scale grassland.

**Consistency checking**

The consistency of the screening process has been tested at the title and abstract stage with 600 publications, which were divided into two groups and screened by three members of the protocol development team in each group. The test articles were retrieved in preliminary searches on Web of Science. After the test screening, the eligibility criteria were discussed among all members of the review team. Having clarified the eligibility criteria, we could resolve the disagreements. The final screening will be divided between two reviewers at the title and abstract level. After double-screening another subset of 300 articles, the consistency between the two reviewers will be reassessed, and if necessary, the eligibility criteria will be further clarified. This procedure will be repeated until we are convinced that the eligibility criteria are interpreted and applied consistently among the two reviewers. At least 10 % of the records will be double screened. After that, the screening will continue in single mode. When assessing the consistency between the two reviewers, Kappa tests will be used. However, we will not define any Kappa value a priori that must be exceeded. The Kappa values will rather be seen as a support to our assessments and will be reported in the systematic review. At the full-text level, all records will be screened by at least two reviewers. An additional file will provide a list of articles excluded at the full-text stage with reasons for exclusion.

**Reporting screening outcomes**

Screening results will be reported using a ROSES diagram. The systematic review will also provide a list of eligible articles plus a list of full text articles excluded with reasons for exclusion.

**Study validity assessment**

Critical appraisal of relevant studies will include an assessment of internal and external validity. The assessment of internal validity will be based on the risk of bias. To assess the risk of bias in individual studies, we will use a modified version of the CEE Critical appraisal tool, version 0.3 [8]. We have chosen to modify the existing tool since we have judged that all criteria and questions within each criterion are not applicable to the planned systematic review. In the modified critical appraisal tool, we consider five criteria (sources of bias). These are confounding biases, selection biases, performance biases, detection biases, and outcome assessment biases. For each source of bias, there is a set of questions which should be answered with “yes”, “no”, or “unclear”. Depending on how the questions are answered, the risk of bias is for each source judged to be “low”, “medium”, “high”, or unclear”. The external validity of the studies is primarily assessed during study eligibility

screening. It is important that the crops being cultivated in the studies are relevant to the stakeholders, and possible crops to grow are governed mainly by the climate and soil properties. Thus, climate and soil properties will be fundamental when assessing the external validity of the crops being grown. Another aspect of external validity that needs to be accounted for is the transferability of study results from small-scale experimental studies (e.g., mesocosms) to actual farming practices. Therefore, we will also record the type and scale of included studies.

**Consistency checking**
Critical appraisal and coding for internal study validity will be carried out by four reviewers, and each study will be critically appraised independently by two reviewers. Disagreements between reviewers will be recorded and reconciled through discussions, seeking to reach a consensus among all reviewers. Metadata needed for the assessment of external validity will be extracted and recorded by two reviewers. To check the consistency between the two reviewers, a subset of studies will be extracted by both reviewers. After the completion of metadata extraction, the two reviewers will check each other's extractions.

**Data extraction strategy**
Outcome data will be recorded in separate Excel files for each article. If repeated measurements have been carried out, the data for all reported time points will be recorded. In cases where outcome data were reported in graphic figures, we will use WebPlotDigitizer [9] to extract data. If necessary and feasible, data will be standardised (e.g., conversion of units) at the analysis stage to allow for direct comparison among studies. All outcome data used in the meta-analysis will be available in an Additional file.

**Meta-data extraction and coding strategy**
The articles included for data extraction will be split into two batches, and two reviewers will extract data from one batch each. Quantitative data and meta-data a will be extracted into a spreadsheet which will be fully available as an additional file in the final systematic review. Data will be recorded as reported in each study.

**Consistency checking**
To check consistency between the reviewers and to detect any mistakes, all articles extracted by one reviewer will be double-checked by the other reviewer. In case of disagreements, consensus will be reached through discussions with the broader review team.

**Potential effect modifiers/reasons for heterogeneity**
The meta-data to be extracted from studies include variables regarding key sources of heterogeneity. The variables were agreed on by the review team based on the team members' expertise. The main reasons for heterogeneity may be different soil parameters like organic carbon (OC) content, moisture, pH, bulk density, degree of decomposition or peat depth, as they mutually influence each other, as well as microbial activity. Further, drainage or groundwater table depth, time since drainage, time since conversion to annual cropland and ley/ perennial fallow, tillage practices, and applied fertilisers and crop residues may affect emissions and will be recorded. Finally, measurement methodologies will be reported to account for differences between studies, although data synthesis will rely on relative differences between intervention and comparator per study.

**Type of synthesis**
The systematic review will present a narrative and, if possible, a quantitative synthesis.

**Narrative synthesis methods**

All included studies will be presented in narrative synthesis tables, including the extracted metadata and risk of bias assessments. Descriptive statistics of key variables, including those that may cause heterogeneity in study findings, will be presented in tables and diagrams.

**Quantitative synthesis methods**
The quantitative synthesis will be carried out through meta-analysis using a random-effects model. We believe the most suitable effect size in our case is the log response ratio (ln R). However, we expect that the included studies will generally have a small number of replicates and that the number of studies in each meta-analysis will be relatively small. Therefore, once the data is extracted, we will test the suitability of ln R using the diagnostic test suggested by Hedges et al. [10] and Lajeunesse [11]. Alternatively, standardised mean difference will be used as effect size. The degree of heterogeneity between study results will be assessed using the I2 statistic. Possible reasons for heterogeneity will be explored through subgroup analyses where, for example, “true” peat soils and lower-carbon organic soils, as defined in the Eligible population paragraph, are compared, as well as mesocosm, incubation experiments, and large lysimeters vs field sites. However, we leave the option open to include the mesocosm experiment in the analysis of field sites in case there will not be enough eligible studies. Meta-analyses will be conducted in R using the Metafor package [12]. Results will be visualised through forest plots and presented in tables.

**Qualitative synthesis methods**
N/A

**Other synthesis methods**
N/A

**Assessment of risk of publication bias**
Provided that a sufficient number of studies are included in the meta-analysis, we will construct funnel plots [13] to assess the risk of publication bias.

**Knowledge gap identification strategy**
N/A

**Demonstrating procedural independence**
The reviewers will not be allowed to assess the validity of their own work.

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

**Funding information**
This systematic review protocol is funded by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas) and the Swedish Board of Agriculture. ML is employed by Formas.

**Author’s contributions**
This systematic review protocol is based on a draft written by AH. ÖB wrote a draft of the Background section. All authors discussed, edited, and added text to the draft. All authors read and approved the final manuscript.

**Acknowledgements**
We thank Matilda Svensson at Formas, who contributed to developing the search strategy and evaluated the search strings.

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## Authors and Affiliations


| Name | Country | Affiliation |
|---|---|---|
| Alena Holzknecht | Sweden | Swedish University of Agricultural Sciences |
| Örjan Berglund | Sweden | Swedish University of Agricultural Sciences |
| ***Magnus Land*** | ***Sweden*** | ***Formas*** |
| Jacynthe Dessureault-Rompré | Canada | Université Laval |
| Lars Elsgaard | Denmark | Aarhus University |
| Kristiina Lång | Finland | Natural Resources Institute Finland (Luke) |


Submitted: Aug 8, 2023 | Published: Aug 10, 2023