SOIL, 9, 89–100, 2023
https://doi.org/10.5194/soil-9-89-2023

SOIL Open Access EGU

Semantics about soil organic carbon storage: DATA4C+, a comprehensive thesaurus and classification of management practices in agriculture and forestry

Kenji Fujisaki[1], **Tiphaine Chevallier**[2], **Antonio Bispo**[1], **Jean-Baptiste Laurent**[3,4], **François Thevenin**[5], **Lydie Chapuis-Lardy**[2,6], **Rémi Cardinael**[3,7,8], **Christine Le Bas**[1], **Vincent Freycon**[9,10], **Fabrice Bénédet**[9,10], **Vincent Blanfort**[11,12], **Michel Brossard**[2], **Marie Tella**[13,14], and **Julien Demenois**[3,15,16]

[1]INRAE, Info&Sols, 45075, Orléans, France
[2]UMR Eco&Sols, IRD, INRAE, CIRAD, Institut Agro, University of Montpellier, Montpellier, France
[3]AIDA, Univ Montpellier, CIRAD, Montpellier, France
[4]CIRAD, UPR AIDA, 34398 Montpellier CEDEX 5, France
[5]Société Khaméos, 34170 Castelnau-le-Lez, France
[6]LMI IESOL, Dakar CP 18524, Senegal
[7]CIRAD, UPR AIDA, Harare, Zimbabwe
[8]Department of Plant Production Sciences and Technologies, University of Zimbabwe, Harare, Zimbabwe
[9]Forêts & Sociétés, University of Montpellier, CIRAD, Montpellier, France
[10]CIRAD, UPR Forêts & Sociétés, 34398 Montpellier, France
[11]CIRAD, UMR SELMET, 34398 Montpellier, France
[12]SELMET, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France
[13]US Analyses, University of Montpellier, CIRAD, Montpellier, France
[14]CIRAD, US Analyses, 34398 Montpellier CEDEX 5, France
[15]CIRAD, UPR AIDA, Turrialba 30501, Costa Rica
[16]CATIE, Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba 30501, Costa Rica

Correspondence: Julien Demenois (julien.demenois@cirad.fr)

Received: 28 March 2022 – Discussion started: 23 May 2022
Revised: 19 December 2022 – Accepted: 9 January 2023 – Published: 10 February 2023

Abstract. Identifying the drivers of soil organic carbon (SOC) stock changes is of the utmost importance to contribute to global challenges like climate change, land degradation, biodiversity loss, or food security. Evaluating the impacts of land use and management practices in agriculture and forestry on SOC is still challenging. Merging datasets or making databases interoperable is a promising way, but still has several semantic challenges. So far, a comprehensive thesaurus and classification of management practices in agriculture and forestry has been lacking, especially while focusing on SOC storage. Therefore, the aim of this paper is to present a first comprehensive thesaurus for management practices driving SOC storage (DATA4C+). The DATA4C+ thesaurus contains 224 classified and defined terms related to land management practices in agriculture and forestry. It is organized as a hierarchical tree reflecting the drivers of SOC storage. It is oriented to be used by scientists in agronomy, forestry, and soil sciences with the aim of uniformizing the description of practices influencing SOC in their original research. It is accessible in Agroportal (http://agroportal.lirmm.fr/ontologies/DATA4CPLUS, last access: 24 March 2022) to enhance its findability, accessibility, interoperability, and reuse by scientists and others such as laboratories or land managers. Future uses of the DATA4C+ thesaurus will be crucial to improve and enrich it, but also to raise the quality of meta-analyses on SOC, and ultimately help policymakers to identify efficient agricultural and forest management practices to enhance SOC storage.

1 Introduction

Soil organic carbon (SOC) represents about 25 % of the potential of natural climate solutions (NCSs) to mitigate climate change (Bossio et al., 2020). Maintaining or increasing SOC stocks can play a significant role to tackle global challenges like climate change, but also land degradation, biodiversity loss, or food security (IPCC, 2019). Identifying and addressing the drivers of SOC stock changes is therefore crucial to contribute to Sustainable Development Goals (e.g., SDGs 2, 13, and 15) adopted by the United Nations in 2015 (UN General Assembly, 2015).

Wiesmeier et al. (2019) reported a large number of drivers at various scales, from climate to soil physico-chemistry, including land use and management practices. Land use and management practices shape carbon inputs and outputs at the plot scale, quality of carbon inputs, and may modify the turnover of soil organic matter (SOM) and SOC stocks (e.g., Fujisaki et al., 2018; Paustian et al., 2016; Poeplau et Don, 2015; Powlson et al., 2016). Evaluating the efficiency of management practices (e.g., no tillage, organic amendments) and improving our understanding of processes involved in SOC storage is still challenging and discussed (Chenu et al., 2019; Erb et al., 2017). Consequently, large datasets are necessary to make a statistically robust analysis of SOC storage and its drivers. In that perspective, the number of systematic reviews or meta-analyses is growing (e.g., Beillouin et al., 2021; Bolinder et al., 2020; Cardinael et al., 2018; Fujisaki et al. 2018). Data-driven soil research and the inference of soil knowledge directly from data by using computational tools and modeling techniques are becoming more and more popular (Wadoux et al., 2020). Merging datasets or making databases interoperable to have global datasets is another promising way forward (e.g., Lawrence et al., 2020; Malhotra et al., 2019; Wieder et al., 2020). Open science (OCDE, 2015) and FAIR, i.e., findability, accessibility, interoperability, reusability-guiding principles (Wilkinson et al., 2016), offer opportunities to explore this path.

However, two conditions for drivers, such as land use and management practices, are compulsory for systematic reviews, meta-analyses, or interoperability of databases on SOC storage. They have to (1) have standard definitions and (2) be homogeneously described. Harden et al. (2018) highlighted the need for harmonized description of land use and management practices. Todd-Brown et al. (2022) emphasized the role that semantics should play to overcome the challenges above. Indeed, there are currently two major limitations for these drivers of SOC change: subjectivity of the semantics and limited scope of the terms. Many global-scale studies do not always clearly define the management practices and use subjective terms like “improved management”, or “best management practices” (Batjes, 2019; Paustian et al., 2016; Smith et al., 2020). Consequently, comparisons between studies might be impossible, as improvement or best management practices are highly context-dependent (i.e., agronomic, climatic, socioeconomic, or time context) (Rosenstock et al., 2016). Reversely, meta-analyses or original studies that evaluate the effect of specific land management practices on SOC storage provide detailed description of the land use and management practices, but their scope is generally limited to one land cover type, one broad category of land management practice, or focus on a climatic zone, a region, or a country (Cardinael et al., 2018; Corbeels et al., 2019; Li et al., 2018; Poeplau and Don, 2015; Maillard and Angers, 2014).

Several standards are available for the description of land cover (e.g., Food and Agriculture Organization (FAO) Land Cover Classification System, System of Environmental–Economic Accounting (SEEA, 2012), LUCAS (Eurostat, 2015)) and more recently of land use (e.g., Intergovernmental Panel on Climate Change, SEEA) (Jansen and DiGregorio, 2002; Pesce et al., 2018). Three standards for farming practices are listed by the Agrisemantics map of data standards (Pesce et al., 2018): a list of agricultural practices established by the FAO (https://vest.agrisemantics.org/node/20351, last access: 24 March 2022), the land-use categories in World Census of Agriculture (https://vest.agrisemantics.org/node/20353, last access: 24 March 2022), and the SEEA Land-use Classification (https://vest.agrisemantics.org/node/20352, last access: 24 March 2022). However, a comprehensive thesaurus and classification of management practices is lacking, especially while focusing on SOC storage. For instance, the standards for ”farming practices” listed in the Agrisemantics map (https://vest.agrisemantics.org/by-theme/7705/7705/7713, last access: 24 March 2022) are not exhaustive (e.g., empirical farmers’ practices in southern countries) nor harmonized or/and specific to SOC storage. As far as we know, there has been no attempt to deal with these shortcomings to be able to understand, quantify, or extrapolate processes and drivers of SOC storage in agriculture and forestry using large databases. Therefore, the objectives of this study were: (i) to compile a comprehensive thesaurus, i.e., a list of standards and specifically defined terms, for management practices driving SOC storage; (ii) to keep such a thesaurus easy to use for non-scientists such as soil test laboratories or land managers; and (iii) to define a classification of these drivers to further enhance interoperability of databases on SOC. The aim of this paper is to present a first comprehensive thesaurus and classification of management practices in agriculture and forestry with a focus on soil organic carbon, called DATA4C+.

2 Materials and methods

2.1 Identification of SOC drivers related to land management practices

In the present work, land management practices covered croplands, grasslands, and forestry practices established at the field scale, without any change in land use. We identified land management practices which are recognized in scientific literature to influence SOC change. The literature search was conducted based on expert knowledge. A first list of meta-analyses was established by the authors, allowing the identification of relevant land management practices (e.g., Cardinael et al., 2018; Mayer et al., 2020; Smith et al., 2020, see Supplement 1 for some examples and Supplement 2 for the full list). Focus was put on meta-analyses as homogeneous definitions are a prerequisite to conduct such analyses. Besides, the list of land management practices gathered from the meta-analyses was completed thanks to technical and institutional reports (e.g., Chotte et al., 2019; Pellerin et al., 2020; Sanz et al., 2017; Smith et al., 2007), which are hardly referenced in search engines like Scopus, Web of Science, or Google Scholar. Finally, this list of practices was extensively discussed among the group of authors, resulting in the selection of other practices than the initial ones.

Only land management practices explicitly described were retained. Therefore, management practices labeled as "improved" were discarded. Agroforestry was considered in this study as a land management practice, since it is defined as an agroecosystem where "forest species of trees and other wooded plants are purposely grown on the same land as agricultural crops or livestock, either concurrently or in rotation" (FAO, 2015).

2.2 Definition of drivers

Definitions of land cover classes, land-use classes, and land management practices were found in data standards (e.g., World Census of Agriculture, FAO, 2015), thesaurus (e.g., Agrovoc), and scientific literature collected at the former step of driver identification. In case a definition was lacking in the primary data source, it was collected through thematic glossaries (e.g., IPCC, 2019; "Landmark Glossary"; "WOCAT Glossary").

2.3 Classification of land management practices

As there is currently no comprehensive thesaurus for land management practices which directly or indirectly affect SOC dynamics, we classified the single management practices gathered in the previous steps into a hierarchical tree. This hierarchical tree was built thanks to existing classifications of land management practices found in literature. These classifications usually rely on the manipulation of several components of the agroecosystem which often affect C inputs and C outputs from soils, such as the plant management,

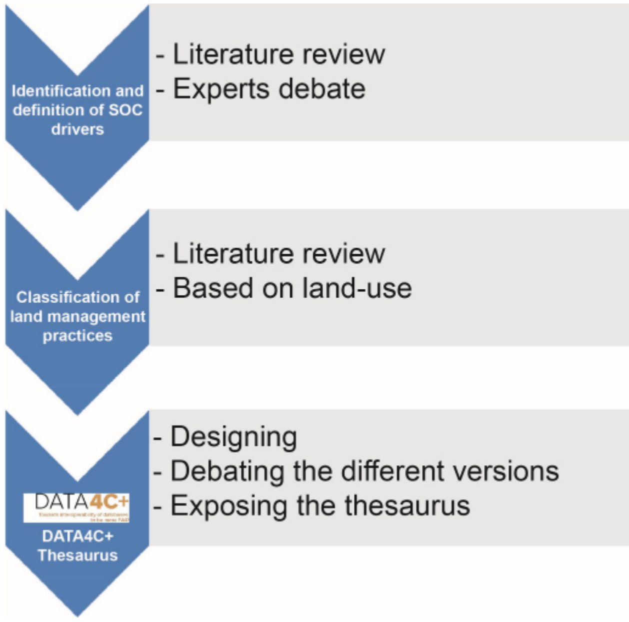

Figure 1. Summary of the different steps to build the DATA4C+ thesaurus.

water management, or soil tillage management for example (Supplement 1). We considered, in the hierarchical tree, only single land management practices. Integrated land management practices (e.g., conservation agriculture, organic agriculture) were not included as a whole but described by their single components (e.g., conservation agriculture means no tillage, permanent soil cover, rotation/crop diversification).

2.4 Design and quality control of the thesaurus

From October 2019 to October 2020, participants of the project DATA4C+ (https://www.data4c-plus-project.fr/en, last access: 24 March 2022) carried out the editing phase of the thesaurus. Participants were junior and senior scientists from three French research institutions (i.e., Cirad, INRAE, IRD) that joined their expertise about organic carbon dynamics in temperate and tropical soils. A first version of the thesaurus and classification was shared and discussed among them in October 2020. The consolidation phase was carried out from November 2020 to June 2021. A second version of the thesaurus and classification was shared, discussed, and validated among participants of the project in July 2021. From July 2021 to September 2021, editors of the thesaurus checked its consistency before its first available online version, as presented in this paper (see Fig. 1).

3 Results

3.1 Land management practices

Land management practices were classified in three main categories according to land use: (i) land management practices in annual and perennial croplands, (ii) land management practices in grasslands, and (iii) land management practices in forests and tree plantations. We chose to classify the land management practices inside large categories of land use rather than land cover for several reasons. Land-use categories are well harmonized between different standards (FAO, IPCC, SEEA, World Census of Agriculture, see Gong et al., 2009), whereas the matching of land cover categories between the main standards is less straightforward (see, for instance, Herold et al. (2009) and Yang et al. (2017) for the harmonization of FAO Land Cover Classification System with other land cover standards). Land-use categories suit well with greenhouse gas (GHG) balance accounting thanks to the IPCC framework (Bernoux et al., 2010; IPCC, 2006). Furthermore, some management practices may induce a change in land cover without changing in land use, such as management practices regarding plant management like agroforestry practices.

In these categories, several subcategories were created regarding plant, biomass (through grazing and animal management in grassland, residue management in croplands, biomass fluxes in forests) and amendments management, but also erosion, water, fire, and land clearing management in the case of agroecosystems implanted after land clearing. These subcategories are mainly inspired from Smith et al. (2020). They rely on management techniques from the point of view of the land managers, which is commonly used in literature for the classification of land management practices that affect SOC dynamics (Supplement 1). Another classification of land management practices could be specifically based on the mechanisms affecting SOC dynamics, i.e., modification of carbon inputs and/or modification of SOM turnover. However, this approach would be less handy for a non-scientific audience. Furthermore, there are still knowledge gaps regarding the processes involved in SOC sequestration after the establishment of several management practices (Chenu et al., 2019).

3.2 The DATA4C+ thesaurus: technology, content, and browsing

The DATA4C+ thesaurus is freely available at the following URL: http://data4c-plus.net/admin/thesaurus/index, last access: 24 March 2022.

The DATA4C+ thesaurus is connected to a PostgreSQL® database. The intuitive web interface uses the jsPlumbTree function of the jQuery library, which is a plugin that renders a reducible and extensible tree structure representing the hierarchical relationship between different nodes. In addition, the plugin uses the jsPlumb library to draw connection lines using Bézier curves between nodes. The tree is drawn dynamically from left to right and top to bottom when connecting to the database.

Each term of the database is defined by four nodes as follows:

- *data-id.* Term identifier. It must be unique throughout the tree.
- *data-parent.* Identifier of the parent node.
- *data-first-child.* Identifier of the first child node.
- *data-next-sibling.* Identifier of the next sibling node.

The DATA4C+ thesaurus was developed by Cirad. All the source programs are available on the forge at https://gitlab.cirad.fr/jean-baptiste.laurent/data4c (Laurent and Thevenin, 2022) and can be freely accessed on request under the CC BY-SA 4.0 FR license. To facilitate reuse of the DATA4C+ thesaurus, it can be downloaded in a Simple Knowledge Organization System (SKOS) format (W3C, 2009). The DATA4C+ thesaurus is accessible in Agroportal (http://agroportal.lirmm.fr/ontologies/DATA4CPLUS, last access: 24 March 2022) to enhance its findability, accessibility, interoperability, and reusability by scientists in agronomy, forestry, and soil sciences. It may also be used by other end users such as soil test laboratories to describe the soil samples analyzed or by land managers to describe and report their practices (e.g., for carbon farming programs). Additionally, the comma separated values (CSVs) file of DATA4C+ thesaurus is available on the data depository of Cirad (https://dataverse.cirad.fr, last access: 24 March 2022) under the CC-BY 4.0 FR license with the https://doi.org/10.18167/DVN1/HMCPMF. The DATA4C+ thesaurus classifies 224 defined terms related to land management practices in agriculture and forestry. It is organized as a hierarchical tree reflecting the drivers of SOC storage. To have access to the definition of a given term, the user must find the term in the tree and click on it. Then, a "pop-up" appears with the definition of the term and the source of the definition (Fig. 2). A link to the source of the definition (URL or DOI) is given for each term. By clicking on this link, a new web page appears.

4 Discussion

4.1 Less subjectivity of land use and management practices will improve reuse of data and quality of meta-analyses

The terms "improved management practice" or "conventional agricultural" are currently used in the scientific literature despite their subjectivity (Sumberg and Giller, 2022). The use of this term implicitly means comparing one practice to another practice and describing the improved actions, which is hardly ever done. The DATA4C+ thesaurus

Table 1. Matching evaluation of land management practices assessed in meta-analyses against land management practices in the DATA4C+ thesaurus.

Source	Land management category in paper	Land management practice evaluated	Land management practice or variable in the DATA4C+ thesaurus
Bai et al. (2019)	Climate Smart Agriculture practices	No till	No till
		Reduced tillage	Intermediate-intensity tillage
		Cover crop	Cover crop
		Biochar	Biochar
	Crop residue	Return	Mulched residues OR shredded residues OR buried residues
		Remove	Exported residues
	Nitrogen fertilization	1–100	Partially covered: mineral fertilization practice is included but not the quantity supplied
		101–200	Partially covered: mineral fertilization practice is included but not the quantity supplied
		>200	Partially covered: mineral fertilization practice is included but not the quantity supplied
	Water management	Irrigation	Irrigation
	Crop sequence	Rotational	Rotation of annual crops
		Continuous	Monoculture
	Cover crop species	*Poaceae*	Not covered in the thesaurus
		Fabaceae	Not covered in the thesaurus
		Poaceae and *Fabaceae*	Not covered in the thesaurus
Conant et al. (2017)	Grassland management	Fertilizer	Mineral fertilization
		Grazing	Several choices required in ”grazing management”
		Sowing improved grass species	Plant breeding
		Grass ley in rotation	Temporary grassland in crop rotation
		Fire	Several choices required in “fire management”
		Earthworms	Not covered in the thesaurus
		Irrigation	Irrigation
		Reclamation	Not covered in the thesaurus
		Silvopastoralism	Silvopastures

Table 1. Continued.

Source	Land management category in paper	Land management practice evaluated	Land management practice or variable in the DATA4C+ thesaurus
Shi et al. (2018)	Agroforestry practices	Alley cropping	Alley cropping
		Home gardens	Multistrata systems
		Silvopastures	Silvopastures
		Windbreaks	Hedgerows
Han et al. (2016)	Crop fertilization	Unbalanced application of chemical fertilizers	Partially covered: mineral fertilization practice is included but not the appreciation of balanced vs. unbalanced application
		Balanced chemical fertilization	Partially covered: mineral fertilization practice is included but not the appreciation of balanced vs. unbalanced application
		Straw retention and application of chemical fertilizers	Mulched residues OR Shredded residues OR Buried residues AND Mineral fertilization
		Application of manure and chemical fertilizers	Solid manure OR liquid manure AND mineral fertilization
Jian et al. (2020)	Tillage group	Disk tillage	High- or intermediate-intensity tillage depending on the depth
		Sweep	High- or intermediate-intensity tillage depending on the depth
		Tandem disk	High- or intermediate-intensity tillage depending on the depth
		Full tilled	High-intensity tillage
		Moldboard ploughing	High-intensity tillage
		Harrowing	Intermediate-intensity tillage
		Moldboard plowing	High-intensity tillage
		Turnplow	High-intensity tillage
		Plow till	High-intensity tillage
		Ridge till	High- or intermediate-intensity tillage depending on the tools and the depth
		Mulch tillage	Intermediate-intensity tillage

Table 1. Continued.

Source	Land management category in paper	Land management practice evaluated	Land management practice or variable in the DATA4C+ thesaurus
Jian et al. (2020)	Tillage group	Chisel	High- or intermediate-intensity tillage depending on the depth
		Slit tillage	High- or intermediate-intensity tillage depending on the depth
		Light tillage	Intermediate-intensity tillage
		Strip tiller tillage	Strip tillage
		Deep till	High-intensity tillage
		No tillage	No till
Jian et al. (2020)	Conservation type	Agriculture forest system	Several choices required in the category "agroforestry"
		Cover crop	Cover crop
		No tillage	No till
		Reduced tillage	Intermediate-intensity tillage
		Organic farm	Organic agriculture
		Straw return, mulching	Mulched residues
		Stubble	Not covered in the thesaurus
		Ridging	High- or intermediate-intensity tillage depending on the tools and the depth
		Rotation	Rotation of annual crops
		Plastic film mulching	Not covered in the thesaurus
		Interplanting	Intercropping
		Combination of two	Not covered in the thesaurus
		Organic farm with cover crop as green manure	Organic agriculture AND cover crop
		Organic farm with no tillage	Organic agriculture AND no till

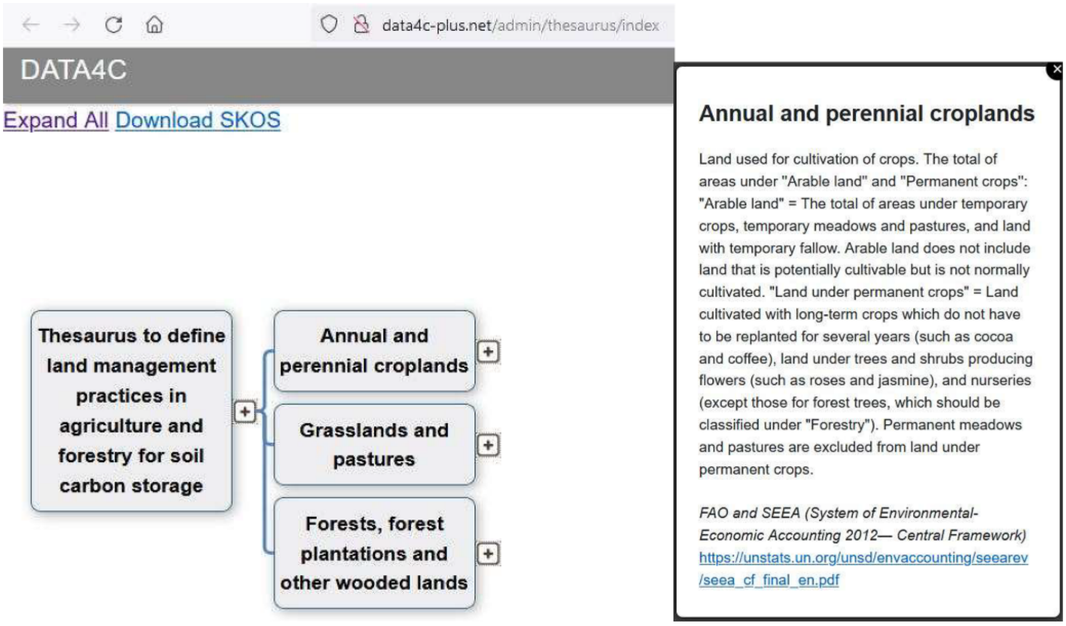

Figure 2. Browsing hierarchical tree and definition in the DATA4C+ thesaurus (http://data4c-plus.net/admin/thesaurus/index, last access: 24 March 2022).

gives a framework to describe the practices. This is vital to produce robust meta-analyses. For instance, the term "improved management of pastures" encompasses diverse agronomic practices (e.g., introduction of leguminous species, switching from mineral to organic fertilizers, no burning for land clearing, reduced grazing intensity). The description of each of these agronomic practices is specific: species' names and plant density for the introduction of leguminous, type, amount and date of application of fertilizers for the switch from mineral to organic fertilizers, and amount of biomass left on site for no burning for land clearing. Besides, their impacts on SOC stocks are highly different, as highlighted by Maia et al. (2009), Conant et al. (2017), or Fujisaki et al. (2018).

4.2 More genericity in the description of management practices will improve reuse of data and quality of meta-analyses

The DATA4C+ thesaurus intends to facilitate data sharing for the evaluation of soil carbon storage through land management practices, thanks to the genericity of the proposed terms. We evaluate the DATA4C+ thesaurus against land management practices used in several meta-analyses (Table 1). In many situations, there is an adequate matching between terms used in the meta-analyses and terms used in the thesaurus.

However, some studies use levels of details uncovered in the thesaurus, such as the species family of plants sown in the fields (Bai et al., 2019), or several tillage techniques (Jian et al., 2020), that can be grouped into larger categories used in the thesaurus (intermediate-intensity tillage or high-intensity tillage). These very detailed levels were not covered in the thesaurus because of the current lack of the evaluation of their effect on SOC dynamics. Indeed, the effect of soil tillage on soil carbon storage is still discussed by soil scientists (Chenu et al., 2019), and the use of numerous categories of tillage practices may weaken the significance of the observed trends. We used in the thesaurus classes of tillage intensity based on the study of Haddaway et al. (2021), which distinguished high-intensity tillage from intermediate-intensity tillage, depending on the inversion or not of the soil during tillage and the performed depth of the tillage practice. This offers, in our opinion, transparent criteria to characterize tillage intensity.

On the other hand, several studies use broader categories than in the present thesaurus, which may prevent reuse of the dataset. This is the case for land management practices in grasslands studied by Conant et al. (2017), where categories such as "grazing" and "fire" are not further detailed, despite the wide response range of soil carbon stocks according to the intensity of grazing for instance (Abdalla et al., 2018).

Concerning meta-analyses of SOC, Beillouin et al. (2022) identified issues of low transparency, reproducibility, and updatability. Improving the quality and reliability of synthesis papers is of utmost importance, as they are increasingly used to inform policy decisions with possibly large environmental and socioeconomic implications (Krupnik et al., 2019). Nosek et al. (2015) noted that advances must be made to give full and unbiased access to scientific data in line with open science practices. In that perspective, the transparency

and the genericity of the terms defined in the DATA4C+ thesaurus, mostly inventoried in original papers and technical and institutional reports, will contribute to increase the quality of data and ultimately to merge and analyze data from various sources.

4.3 Future development of the DATA4C+ thesaurus: uses and accrual

The DATA4C+ thesaurus is expected to be used by scientists in agronomy, forestry, and soil sciences, with the aim of uniformizing the description of practices influencing SOC in their original research. As it was developed to be simple and easy to use, the thesaurus may also be used by several end users, like land managers (e.g., to report their practices for carbon farming), or by laboratories to describe the soil samples analyzed (e.g., metadata on the sample). The generated data will therefore be more easy to retrieve and integrated to perform meta-analyses in particular. Another perspective will be to mobilize the DATA4C+ thesaurus to feed models on SOC dynamics with more site-specific data. However, such a perspective would need to enrich the DATA4C+ thesaurus with vocabulary related to annual carbon inputs to enhance carbon inputs to soil (e.g., Bolinder et al., 2007). Accrual of the DATA4C+ thesaurus could also be focused on emerging practices and empirical farmers' practices, which are poorly studied by researchers. Promotion and peer reviewing of the updated versions of the DATA4C+ thesaurus will be performed by the Scientific and Technical Committee of the 4 per 1000 Initiative (https://4p1000.org/, last access: 24 March 2022). Versioning of the DATA4C+ thesaurus will be done at the following URL: http://data4c-plus.net/admin/thesaurus/index, last access: 24 March 2022, in Agroportal (http://agroportal.lirmm.fr/ontologies/DATA4CPLUS, last access: 24 March 2022) and on the data repository of Cirad (https://doi.org/10.18167/DVN1/HMCPMF). Suggestions of accrual could be sent to the corresponding author or at the following email address: data4c@cirad.fr.

5 Conclusions

The DATA4C+ thesaurus is the first attempt to compile and classify the land use and management practices in agriculture and forestry that influence SOC storage. Future uses of the DATA4C+ thesaurus will be crucial to improve and enrich it, but also to raise the quality of meta-analyses on SOC, and ultimately help policymakers to identify efficient agricultural and forest management practices to improve SOC storage. In that sense, the DATA4C+ thesaurus is a contribution to SDG 17 "Partnerships for the goals" (i.e., goals 17.6 and 17.7).

Code availability. The DATA4C+ thesaurus was developed by Cirad and Khaméos. All the source programs are available on the forge https://gitlab.cirad.fr/jean-baptiste.laurent/data4c (Laurent and Thevenin, 2022) and can be freely accessed on request under the CC BY-SA 4.0 FR license.

Data availability. The DATA4C+ thesaurus is accessible in Agroportal (http://agroportal.lirmm.fr/ontologies/DATA4CPLUS, last access: 24 March 2022; Demenois et al., 2022). The CSV file of the DATA4C+ thesaurus is available on the repository of Cirad in the Dataverse CIRAD (https://dataverse.cirad.fr, last access: 24 March 2022) under the CC-BY 4.0 FR license with the DOI https://doi.org/10.18167/DVN1/HMCPMF (Demenois et al., 2022).

Supplement. A full list of references and technical and institutional reports used to identify the land management practices is included in the Supplement. The supplement related to this article is available online at: https://doi.org/10.5194/soil-9-89-2023-supplement.

Author contributions. KF led the inventory and analyses of resources to build the thesaurus. FT and JBL did the informatic development of the thesaurus. AB, TC, and JD supervised the conceptualization of the thesaurus. KF and JD prepared the paper with contributions from all the co-authors. All the co-authors reviewed the thesaurus and the paper.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Disclaimer. Publisher's note: Copernicus Publications remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Acknowledgements. We would like to thank colleagues from Agroportal for their technical help in publishing the DATA4C+ thesaurus. We are grateful to the reviewers who made constructive comments and helped improve the paper.

Financial support. Support was provided by the French National Research Agency (ANR, https://anr.fr/, last access: 24 March 2022) through the project DATA4C+ "Towards interoperability of databases to be more FAIR" (https://www.data4c-plus-project.fr/en, last access: 24 March 2022) (grant no. ANR-19-DATA-0005-01). The DATA4C+ project is led by the CIRAD-INRAE-IRD consortium. The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the paper.

Review statement. This paper was edited by Jeanette Whitaker and reviewed by Jonathan Sanderman and one anonymous referee.

References

Abdalla, M., Hastings, A., Chadwick, D. R., Jones, D. L., Evans, C. D., Jones, M. B., Rees, R. M., and Smith, P.: Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands, Agr. Ecosyst. Environ., 253, 62–81, https://doi.org/10.1016/j.agee.2017.10.023, 2018.

Bai, X., Huang, Y., Ren, W., Coyne, M., Jacinthe, P.-A., Tao, B., Hui, D., Yang, J., and Matocha, C.: Responses of soil carbon sequestration to climate-smart agriculture practices: A meta-analysis, Glob. Change Biol., 25, 2591–2606, https://doi.org/10.1111/gcb.14658, 2019.

Batjes, N. H.: Technologically achievable soil organic carbon sequestration in world croplands and grasslands, Land Degrad. Dev., 30, 25–32, https://doi.org/10.1002/ldr.3209, 2019.

Beillouin, D., Cardinael, R., Berre, D., Boyer, A., Corbeels, M., Fallot, A., Feder, F., and Demenois, J.: A global overview of studies about land management, land-use change, and climate change effects on soil organic carbon, Glob. Change Biol., 28, 1690-1702, https://doi.org/10.1111/gcb.15998, 2022.

Bernoux, M., Branca, G., Carro, A., Lipper, L., Smith, G., and Bockel, L.: Ex-ante greenhouse gas balance of agriculture and forestry development programs, Sci. Agr., 67, 31–40, https://doi.org/10.1590/S0103-90162010000100005, 2010.

Bolinder, M. A., Janzen, H. H., Gregorich, E. G., Angers, D. A., and VandenBygaart, A. J.: An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada, Ag. Ecosyst. Environ., 118, 29–42, https://doi.org/10.1016/j.agee.2006.05.013, 2007.

Bolinder, M. A., Crotty, F., Elsen, A., Frac, M., Kismányoky, T., Lipiec, J., Tits, M., Tóth, Z., and Kätterer, T.: The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: a synthesis of reviews, Mitig. Adapt. Strateg. Glob. Chang., 25, 929–952, https://doi.org/10.1007/s11027-020-09916-3, 2020.

Bossio, D. A., Cook-Patton, S. C., Ellis, P. W., Fargione, J., Sanderman, J., Smith, P., Wood, S., Zomer, R. J., Von Unger, M., and Emmer, I. M.: The role of soil carbon in natural climate solutions, Nat. Sustain., 3, 391–398, https://doi.org/10.1038/s41893-020-0491-z, 2020.

Cardinael, R., Umulisa, V., Toudert, A., Olivier, A., Bockel, L., and Bernoux, M.: Revisiting IPCC Tier 1 coefficients for soil organic and biomass carbon storage in agroforestry systems, Environ. Res. Lett., 13, 124020, https://doi.org/10.1088/1748-9326/aaeb5f, 2018.

Chenu, C., Angers, D. A., Barré, P., Derrien, D., Arrouays, D., and Balesdent, J.: Increasing organic stocks in agricultural soils: Knowledge gaps and potential innovations, Soil Till. Res., 188, 41–52, https://doi.org/10.1016/j.still.2018.04.011, 2019.

Chotte, J. L., Aynekulu, E., Cowie, A., Campbell, E., Vlek, P., Lal, R., Kapovic-Solomun, M., Von Maltitz, G. P., Kust, G., and Barger, N.: Realising the carbon benefits of sustainable land management practices: Guidelines for estimation of soil organic carbon in the context of land degradation neutrality planning and monitoring, A report of the Science-Policy Interface, United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany, https://catalogue.unccd.int/1209_UNCCD_SPI_2019_Report_1.1.pdf (last access: 24 March 2022), 2019.

Conant, R. T., Cerri, C. E. P., Osborne, B. B., and Paustian, K.: Grassland management impacts on soil carbon stocks: a new synthesis, Ecol. Appl., 27, 662–668, https://doi.org/10.1002/eap.1473, 2017.

Corbeels, M., Cardinael, R., Naudin, K., Guibert, H., and Torquebiau, E.: The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-Saharan Africa, Soil Till. Res., 188, 16–26, https://doi.org/10.1016/j.still.2018.02.015, 2019.

Demenois, J., Fujisaki, K., Chevallier, T., Bispo, A., Laurent, J.-B., Thévenin, F., Chapuis-Lardy, L., Cardinael, R., Freycon, V., Bénédet, F., Le Bas, C., Tella, M., Blanfort, V., and Brossard, M.: DATA4C+ – A thesaurus to define land management practices in agriculture and forestry for soil carbon storage, CIRAD Dataverse [data set], https://doi.org/10.18167/DVN1/HMCPMF, 2022.

Erb, K.-H., Luyssaert, S., Meyfroidt, P., Pongratz, J., Don, A., Kloster, S., Kuemmerle, T., Fetzel, T., Fuchs, R., Herold, M., Haberl, H., Jones, C. D., Marín-Spiotta, E., McCallum, I., Robertson, E., Seufert, V., Fritz, S., Valade, A., Wiltshire, A., and Dolman, A. J.: Land management: data availability and process understanding for global change studies, Glob. Change Biol., 23, 512–533, https://doi.org/10.1111/gcb.13443, 2017.

Eurostat: LUCAS Technical reference document C3 Classification (Land cover and Land-use), 93 pp.,. https://ec.europa.eu/eurostat/documents/205002/6786255/ (last access: 24 March 2022), 2015.

FAO: World Programme for the Census of Agriculture 2020, Vol. 1, Programme, Concepts and Definitions, FAO, Rome, https://www.fao.org/3/i4913e/i4913e.pdf (last access: 24 March 2022), 2015.

Fujisaki, K., Chevallier, T., Chapuis-Lardy, L., Albrecht, A., Razafimbelo, T., Masse, D., Ndour, Y. B., and Chotte, J.-L.: Soil carbon stock changes in tropical croplands are mainly driven by carbon inputs: A synthesis, Agr. Ecosyst. Environ., 259, 147–158, https://doi.org/10.1016/j.agee.2017.12.008, 2018.

Gong, X., Marklund, L. G., and Tsuji, S.: Land-use classification proposed to be used in the SEEA, in: 14th Meeting of the London Group on Environmental Accounting, 27–30 April 2009, Canberra, LG/14/10, https://unstats.un.org/unsd/envaccounting/londongroup/meeting14/LG14_10a.pdf (last access: 24 March 2022), 2009.

Haddaway, N. R., Hedlund, K., Jackson, L. E., Kätterer, T., Lugato, E., Thomsen, I. K., Jørgensen, H. B., and Isberg, P.-E.: How does tillage intensity affect soil organic carbon? A systematic review, Environ. Evid., 6, 30, https://doi.org/10.1186/s13750-017-0108-9, 2017.

Harden, J. W., Hugelius, G., Ahlström, A., Blankinship, J. C., Bond-Lamberty, B., Lawrence, C. R., Loisel, J., Malhotra, A., Jackson, R. B., Ogle, S., Phillips, C., Ryals, R., Todd-Brown, K., Vargas, R., Vergara, S. E., Cotrufo, M. F., Keiluweit, M., Heckman, K. A., Crow, S. E., Silver, W. L., DeLonge, M., and Nave, L. E.: Networking our science to characterize the state, vulnerabilities, and management opportunities of soil organic matter, Glob. Change Biol., 24, e705–e718, https://doi.org/10.1111/gcb.13896, 2018.

Herold, M., Hubald, R., and Di Gregorio, A.: Translating and evaluating land cover legends using the UN Land Cover Classification

System (LCCS), GOGC-GOLD Report 43, https://gofcgold.umd.edu/sites/default/files/docs/ReportSeries/GOLD_43.pdf (last access: 24 March 2022), 2009.

IPCC: IPCC Guidelines for national greenhouse gas inventories, Prepared by the National Greenhouse Gas Inventories Programme, edited by: Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K., Hayama, Kanagawa, Japan, https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (last access: 24 March 2022), 2006.

IPCC: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, edited by: Shukla, P. R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D. C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., and Malley, J., https://www.ipcc.ch/srccl/ (last access: 24 March 2022), 2019.

Jansen, L. J. M. and Gregorio, A. D.: Parametric land cover and land-use classifications as tools for environmental change detection, Agr. Ecosyst. Environ., 91, 89–100, https://doi.org/10.1016/S0167-8809(01)00243-2, 2002.

Jian, J., Du, X., and Stewart, R. D.: A database for global soil health assessment, Sci. Data, 7, 16, https://doi.org/10.1038/s41597-020-0356-3, 2020.

Krupnik, T. J., Andersson, J. A., Rusinamhodzi, L., Corbeels, M., Shennan, C., and Gérard, B.: Does size matter? a critical review of meta-analysis in agronomy, Exp. Agr., 55, 200–229, https://doi.org/10.1017/S0014479719000012, 2019.

Laurent, J.-B. and Thevenin, F.: DATA4C+ thesaurus programs, GitLab [code], https://gitlab.cirad.fr/jean-baptiste.laurent/data4c, last access: 24 March 2022.

Lawrence, C. R., J. Beem-Miller, Hoyt, A. M., Monroe, G., Sierra, C. A., Stoner, S., Heckman, K., Blankinship, J. C., Crow, S. E., McNicol, G., Trumbore, S., Levine, P. A., Vindušková, O., Todd-Brown, K., Rasmussen, C., Hicks Pries, C.E., Schädel, C., McFarlane, K., Doetterl, S., Hatté, C., He, Y., Treat, C., Harden, J. W., Torn, M. S., Estop-Aragonés, C., Asefaw Berhe, A., Keiluweit, M., Della Rosa Kuhnen, Á., Marin-Spiotta, E., Plante, A. F., Thompson, A., Shi, Z., Schimel, J. P., Vaughn, L. J. S., von Fromm, S. F., and Wagai, R.: An open-source database for the synthesis of soil radiocarbon data: International Soil Radiocarbon Database (ISRaD) version 1.0, Earth Syst. Sci. Data, 12, 61–76, https://doi.org/10.5194/essd-12-61-2020, 2020.

Li, Y., Shi, S., Waqas, M. A., Zhou, X., Li, J., Wan, Y., Qin, X., Gao, Q., Liu, S., and Wilkes, A.: Long-term (≥20 years) application of fertilizers and straw return enhances soil carbon storage: a meta-analysis, Mitig. Adapt. Strateg. Glob. Chang., 23, 603–619, https://doi.org/10.1007/s11027-017-9751-2, 2018.

Maia, S. M. F., Ogle, S. M., Cerri, C. E. P., and Cerri, C. C.: Effect of grassland management on soil carbon sequestration in Rondônia and Mato Grosso states, Brazil, Geoderma, 149, 84–91, https://doi.org/10.1016/j.geoderma.2008.11.023, 2009.

Maillard, É. and Angers, D. A.: Animal manure application and soil organic carbon stocks: a meta-analysis, Glob. Change Biol., 20, 666–679, https://doi.org/10.1111/gcb.12438, 2014.

Malhotra, A., Todd-Brown, K., Nave, L. E., Batjes, N. H., Holmquist, J. R., Hoyt, A. M., Iversen, C. M., Jackson, R. B., Lajtha, K., Lawrence, C., Vindušková, O., Wieder, W., Williams, M., Hugelius, G., and Harden, J.: The landscape of soil carbon data: Emerging questions, synergies and databases, Prog. Phys. Geogr. Earth Environ., 43, 707–719, https://doi.org/10.1177/0309133319873309, 2019.

Mayer, M., Prescott, C. E., Abaker, W. E. A., Augusto, L., Cécillon, L., Ferreira, G. W. D., James, J., Jandl, R., Katzensteiner, K., Laclau, J.-P., Laganière, J., Nouvellon, Y., Paré, D., Stanturf, J. A., Vanguelova, E. I., and Vesterdal, L.: Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis, Forest Ecol. Manag., 466, 118127, https://doi.org/10.1016/j.foreco.2020.118127, 2020.

Nosek, B. A., Alter, G., Banks, G. C., Borsboom, D., Bowman, S. D., Breckler, S. J., Buck, S., Chambers, C. D., Chin, G., Christensen, G., Contestabile, M., Dafoe, A., Eich, E., Freese, J., Glennerster, R., Goroff, D., Green, D. P., Hesse, B., Humphreys, M., Ishiyama, J., Karlan, D., Kraut, A., Lupia, A., Mabry, P., Madon, T., Malhotra, N., Mayo-Wilson, E., McNutt, M., Miguel, E., Levy Paluck, E., Simonsohn, U., Soderberg, C., Spellman, B. A., Turitto, J., VandenBos, G., Vazire, S., Wagenmakers, E. J., Wilson, R., and Yarkoni, T.: Promoting an open research culture, Science, 348, 1422–1425, https://doi.org/10.1126/science.aab2374, 2015.

OCDE: “Making Open Science a Reality”, OECD Science, Technology and Industry Policy Papers, no. 25, Éditions OCDE, Paris, https://doi.org/10.1787/5jrs2f963zs1-en, 2015.

Paradelo, R., Virto, I., and Chenu, C.: Net effect of liming on soil organic carbon stocks: A review, Agr. Ecosyst. Environ., 202, 98–107, https://doi.org/10.1016/j.agee.2015.01.005, 2015.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., and Smith, P.: Climate-smart soils, Nature, 532, 49–57, https://doi.org/10.1038/nature17174, 2016.

Pellerin, S., Bamière, L., Launay, C., Martin, R., Schiavo, M., Angers, D., Augusto, L., Balesdent, J., Basile-Doelsch, I., and Bellassen, V. : Stocker du carbone dans les sols français. Quel potentiel au regard de l’objectif 4 pour 1000 et à quel coût ? (Rapport scientifique de l’étude), INRA, France, https://www.inrae.fr/sites/default/files/pdf/RapportEtude4p1000.pdf (last access: 24 March 2022), 2020.

Pesce, V., Tennison, J., Mey, L., Jonquet, C., Toulet, A., Aubin, S., and Panagiotis, Z.: A map of agri-food data standards, https://hal-lirmm.ccsd.cnrs.fr/lirmm-01964791/document (last access: 24 March 2022), 2018.

Poeplau, C. and Don, A.: Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis, Agr. Ecosyst. Environ., 200, 33–41, https://doi.org/10.1016/j.agee.2014.10.024, 2015.

Powlson, D. S., Stirling, C. M., Thierfelder, C., White, R. P., and Jat, M. L.: Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems?, Agr. Ecosyst. Environ., 220, 164–174, https://doi.org/10.1016/j.agee.2016.01.005, 2016.

Rosenstock, T. S., Lamanna, C., Chesterman, S., Bell, P., Arslan, A., Richards, M., Rioux, J., Akinleye, A. O., Champalle, C., Cheng, Z., Corner-Dolloff, C., Dohn, J., English, W., Eyrich, A.-S., Girvetz, E. H., Kerr, A., Lizarazo, M., Madalinska, A.,McFatridge, S., Morris, K. S., Namoi, N., Poultouchidou, A., Ravina da Silva, M, Rayess, S., Ström, H., Tully K. L., and Zhou, W.: The scientific basis of climate-smart agriculture: A systematic review protocol. CCAFS Working Paper no. 136, CGIAR

Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark, https://cgspace.cgiar.org/bitstream/handle/10568/70967/CCAFSWP138.pdf (last access: 24 March 2022), 2016.

Sanz, M. J., De Vente, J., Chotte, J.-L., Bernoux, M., Kust, G. S., Ruiz, I., Almagro, M., Alloza, J.-A., Vallejo, R., and Castillo, V.: Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation, A Report of the Science-Policy Interface, United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany, 178 pp., https://www.unccd.int/sites/default/files/documents/2017-09/UNCCD_Report_SLM_web_v2.pdf (last access: 24 March 2022), 2017.

SEEA: System of Environmental-Economic Accounting 2012: Central Framework. United Nations, European Commission, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, World Bank, 378 pp., https://unstats.un.org/unsd/envaccounting/seearev/seea_cf_final_en.pdf (last access: 24 March 2022), 2012.

Shi, L., Feng, W., Xu, J., and Kuzyakov, Y.: Agroforestry systems: Meta-analysis of soil carbon stocks, sequestration processes, and future potentials, Land Degrad. Dev., 29, 3886–3897, https://doi.org/10.1002/ldr.3136, 2018.

Smith, P., Martino, D., Cai, Z., O'Mara, F., Rice, C., Scholes, B., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Rose, S., Schneider, U., Towprayoon, S., Wattenbach, M., Rypdal, K., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., and Sirotenko, O.: Agriculture, in: Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Metz, B., Davidson, O. R., Bosch, P. R., Dave, R., Meyer, L. A., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 44 pp., https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg3-chapter8-1.pdf (last access: 24 March 2022), 2007.

Smith, P., Calvin, K., Nkem, J., Campbell, D., Cherubini, F., Grassi, G., Korotkov, V., Hoang, A. L., Lwasa, S., McElwee, P., Nkonya, E., Saigusa, N., Soussana, J.-F., Taboada, M. A., Manning, F. C., Nampanzira, D., Arias-Navarro, C., Vizzarri, M., House, J., Roe, S., Cowie, A., Rounsevell, M., and Arneth, A.: Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification?, Glob. Change Biol., 26, 1532–1575, https://doi.org/10.1111/gcb.14878, 2020.

Sumberg, J. and Giller, K. E.: What is 'conventional' agriculture?, Glob. Food Sec., 32, 100617, https://doi.org/10.1016/j.gfs.2022.100617, 2022.

Todd-Brown, K. E. O., Abramoff, R. Z., Beem-Miller, J., Blair, H. K., Earl, S., Frederick, K. J., Fuka, D. R., Guevara Santamaria, M., Harden, J. W., Heckman, K., Heran, L. J., Holmquist, J. R., Hoyt, A. M., Klinges, D. H., LeBauer, D. S., Malhotra, A., McClelland, S. C., Nave, L. E., Rocci, K. S., Schaeffer, S. M., Stoner, S., van Gestel, N., von Fromm, S. F., and Younger, M. L.: Reviews and syntheses: The promise of big diverse soil data, moving current practices towards future potential, Biogeosciences, 19, 3505–3522, https://doi.org/10.5194/bg-19-3505-2022, 2022.

UN General Assembly: Transforming our world: the 2030 Agenda for Sustainable Development, 21 October 2015, A/RES/70/1, https://www.refworld.org/docid/57b6e3e44.html (last access: 24 March 2022), 2015.

W3C: SKOS Simple Knowledge Organization System Reference, W3C Recommendation 18 August 2009, https://www.w3.org/TR/skos-reference/ (last access: 24 March 2022), 2009.

Wadoux, A. M.-C., Román-Dobarco, M., and McBratney, A. B.: Perspectives on data-driven soil research, Eur. J. Soil Sci., 72, 1–15, https://doi.org/10.1111/ejss.13071, 2020.

Wieder, W. R., Pierson, D., Earl, S., Lajtha, K., Baer, S. G., Ballantyne, F., Berhe, A. A., Billings, S. A., Brigham, L. M., Chacon, S. S., Fraterrigo, J., Frey, S. D., Georgiou, K., de Graaff, M.-A., Grandy, A. S., Hartman, M. D., Hobbie, S. E., Johnson, C., Kaye, J., Kyker-Snowman, E., Litvak, M. E., Mack, M. C., Malhotra, A., Moore, J. A. M., Nadelhoffer, K., Rasmussen, C., Silver, W. L., Sulman, B. N., Walker, X., and Weintraub, S.: SoDaH: the SOils DAta Harmonization database, an open-source synthesis of soil data from research networks, version 1.0, Earth Syst. Sci. Data, 13, 1843–1854, https://doi.org/10.5194/essd-13-1843-2021, 2021.

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lützow, M., Marin-Spiotta, E., van Wesemael, B., Rabot, E., Ließ, M., Garcia-Franco, N., Wollschläger, U., Vogel, H.-J., and Kögel-Knabner, I.: Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales, Geoderma 333, 149–162, https://doi.org/10.1016/j.geoderma.2018.07.026, 2019.

Wilkinson, M., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., Bonino da Silva Santos, L., Boume, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., Gonzalez-Beltran, A., Gray, A. J. G., Groth, P., Goble, C., Grethe, J. S., Heringa, J., t'Hoeen, P. A. C., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S. J., Martone, M. E., Mons, A., Packer, A. L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M. A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., and Mons, B.: The FAIR Guiding Principles for scientific data management and stewardship, Sci. Data, 3, 160018, https://doi.org/10.1038/sdata.2016.18, 2016.

Yang, H., Li, S., Chen, J., Zhang, X., and Xu, S.: The Standardization and Harmonization of Land Cover Classification Systems towards Harmonized Datasets: A Review, ISPRS Int. J. Geo.-Inf., 6, 154 https://doi.org/10.3390/ijgi6050154, 2017.