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Guidelines for improved quantification and reporting of carbon stocks and additional carbon storage in agroforestry systems

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Abstract The number of scientific publications related to biomass carbon or soil organic carbon under various land management practices has globally and dramatically increased during the last two decades, the same applies to the peer reviewed *Agroforestry Systems* journal. However, the quality of papers on carbon sequestration in agroforestry systems is very heterogeneous, and many studies do not fulfil simple requirements that would ensure the scientific value of these studies, resulting in high rates of rejections before and after review. The aim of this paper, co-authored by the Editor-in-Chief and Associate Editors of the *Agroforestry Systems* journal is to provide some basic guidelines to improve the quantification and reporting of carbon stocks and additional carbon storage in agroforestry systems, and to maximize manuscript acceptance. These guidelines are also of use for any other international peer-reviewed journal publishing studies on this topic. We also provide a checklist, for both authors and reviewers, of compulsory and recommended variables to be included before submission of an original study related to soil and/or biomass carbon stocks and sequestration in agroforestry systems.

Keywords Soil organic carbon · Biomass · Carbon sequestration · Measurement reporting and verification · Climate change mitigation

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Reporting C sequestration in agroforestry systems is urgent, but challenging

Tackling climate change requires a massive reduction in global CO_2 emissions and a simultaneous deployment of CO_2 removal methods (IPCC 2018). Agriculture, forestry and other land use (AFOLU) activities account for 23% of the total net anthropogenic greenhouse gas (GHG) emissions (IPCC 2019a). Additionally, AFOLU activities play an important role in preserving carbon-rich ecosystems, including peatlands, mangroves, and old-growth forests (Goldstein et al. 2020), to prevent further carbon losses due to land use change (Beillouin et al. 2023), but also to restore carbon stocks in degraded ecosystems (Cook-Patton et al. 2021). Natural climate solutions are deliberate nature-based actions that increase carbon storage and/or avoid greenhouse gas emissions by protecting, restoring, and improving the management of ecosystems, including agricultural lands. They are proposed to contribute to the objective of the 2015 Paris Agreement towards achieving a global goal of net zero emissions by 2050 (Griscom et al. 2017). Agroforestry systems can be part of these natural and sustainable climate solutions (Skole et al. 2021; Terasaki Hart et al. 2023). The 2019 refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories explicitly included for the first-time default emission factors for a range of agroforestry systems (Cardinael et al. 2018a; Ogle et al. 2019) at global scale. Several studies have estimated the global carbon sequestration potential of agroforestry systems, mainly with a focus on carbon accumulated in biomass (Chapman et al. 2020; Zomer et al. 2022). This is a good starting point but estimated values remain uncertain and are likely to provide an underestimation due to the difficulty to differentiate agroforests from forests in humid tropical regions despite modern remote sensing technologies (Terasaki Hart et al. 2023). Agroforestry systems are also one of the best management practices to increase soil organic carbon (SOC) stocks in croplands and grasslands (Cardinael et al. 2017; Beillouin et al. 2023), but many challenges have to be overcome to obtain reliable estimates. Due to the climate change emergency, the number of scientific publications on biomass carbon or SOC has globally increased dramatically during the last two decades (Beillouin et al. 2022). For instance, the peer-reviewed *Agroforestry Systems* journal received 55 papers on this topic during the last 10 months (January–October 2024), with "Carbon Stocks", "C sequestration" or "Soil Organic Carbon" in the titles. More than 50% of these papers were rejected without review due to clear flaws in the methodology. The quality of papers on carbon sequestration in agroforestry systems is very heterogeneous, and many studies do not fulfil simple requirements that would ensure their scientific value (Nair and Nair 2014). There should be a clear objective to the study but equally important the study should be governed by well defined and testable hypotheses. The latter is often lacking and thus many studies are rather a 'test and see' approach than a rigorous scientific study. The aim of this paper is to provide some basic guidelines to improve the quantification and reporting of carbon stocks and additional carbon storage in agroforestry systems, and to maximize manuscript acceptance in the *Agroforestry Systems* journal. These guidelines are also of use for any other international peer-reviewed journal publishing studies on this topic. In Table 1, we provide a checklist, for both authors and reviewers, of compulsory and recommended variables before submission of an original study related to soil and/or biomass carbon stocks and sequestration in agroforestry systems.

Study site description

Precise GPS coordinates

The exact location of the agroforestry study sites must be provided. Firstly, because of transparency and reproducibility of the study as well as enabling follow-up studies to investigate long-term effects. Secondly, because an absence of precise GPS coordinates prevents study site identification in aerial imagery or their use as training data for spatial modelling efforts (Terasaki Hart et al. 2023). In a recent study on the potential of agroforestry systems as a natural climate solution, Terasaki Hart et al. (2023) found that less than 50% of the 465 reviewed studies reported coordinates to at least three decimal places of coordinate precision. As a reminder, one decimal place (0.1 degrees) is equivalent to a precision of 11.1 km, two decimal places (0.01 degrees) to 1.11 km, three

Table 1 Checklist of compulsory and recommended variables before submission of an original study related to soil and/or biomass carbon stocks and sequestration in agroforestry systems

Variables	Compulsory	Recommended
Study site description		
Precise GPS coordinates	X	
Soil type	X	
Soil texture	X	
Soil pH		X
CEC and soil chemical parameters		X
Slope	X	
Catena description[a]	X	
Site history	X	
Elevation	X	
Mean annual rainfall	X	
Mean annual temperature	X	
Köppen climate		X
Experiment design	X	
Agroforestry design	X	
Plantation date/age of the agroforestry system[b]	X	X
Duration and number of the tree rotations[c]	X	
Total tree density	X	
Tree species	X	
Tree density of each tree species	X	
Tree management	X	
Crop and soil management	X	
Livestock management	X	
Carbon in biomass		
Method used to estimate biomass	X	
Allometric equations (source and relevance)[d]	X	
Diameter at breast height	X	
Tree height		X
Total basal area of each tree species		X
Method for biomass carbon concentration	X	
Method for wood density[e]	X	
Time averaged biomass C stock[f]	X	
Carbon in soils		
Bulk density and associated method	X	
Stone content (coarse mass fraction) considered	X	
SOC concentration and associated method	X	
SOC stocks at equivalent soil mass	X	
Approach used (chronosequence, synchronic, diachronic)	X	
Spatial heterogeneity accounted for in sampling design	X	
Sampling depth ≥ 30 cm		X
Several depth increments		X
Sampling dates	X	
Annual and cumulative carbon inputs to the soil[g]	X	X

[a]For landscape based studies

[b]Compulsory if carbon accumulation rates are calculated

[c]A given agroforestry system can include several tree rotations that differ from the age of the system. For example, an agroforestry system can be 40 years old, but tree harvested at 30 years and planted again, soil sampling done at year 10 of the second rotation (corresponding to year 40 of the system)

[d]If allometric equations were used.

[e]If wood density was estimated or measured

[f]If tree plantation rotations are compared (e.g. eucalyptus, rubber, cacao, etc.)

[g]Compulsory for carbon inputs related to crop and tree management (manure, tree prunings, etc.), recommended for other often estimated organic carbon inputs (crop residues, root biomass, etc.)

decimal places (0.001) to 111 m, etc. Therefore, we recommend that agroforestry study sites should be reported with *at least three decimal places* of coordinate precision. For example, the location of the long-term agroforestry experiment in France reported by Cardinael et al. (2015a) should at least be reported as 43.704°N, 3.862°E. In countries with a Land Parcel Identification System as in the European Union, the nationally recognised code of the parcel could also be shared in addition to the GPS coordinates.

Pedo-climatic context

Many studies still provide no or limited information on soil type. Providing soil classification is crucial to understand the results and to extend the results of research. It is therefore required that the authors provide information regarding the *soil type* of the study site using one of the two internationally used *soil classification systems* (Hartemink 2015), either *Soil Taxonomy* (Soil Survey Staff 2014) or *World Reference Base for Soil Resources* (IUSS Working Group WRB 2014). In addition to the soil type, *soil texture*, e.g., sand, silt and clay content, is essential information needed to compare different systems and to assess potential changes in SOC stocks. This is because soil texture strongly influences the soil's carbon sequestration potential and hence is closely related to soil carbon concentration and carbon saturation (Albrecht et al. 2004). Additionally, differences in clay mineralogy (high/low activity clays)/volcanic formations (e.g., the presence of allophane) further influence carbon sequestration potentials. Next to soil type and soil texture, *bulk density* is an essential parameter which is required for any meaningful reporting on SOC stocks or changes. Additional basic soil properties including pH, soil nutrient status and/or cation exchange capacity are very useful and authors are encouraged to share as much information about the study site as they have. The *slope* of the study site should also be indicated. Agroforestry systems can have a strong positive effect on erosion control, especially on sloping areas, and therefore have an indirect effect on SOC stocks (apparent SOC sequestration).

Basic *climate-related data* should also be provided, such as mean annual rainfall and temperature, and Köppen climate, in addition to the elevation. For landscape-based studies, a proper description of the catena is additionally important. Catenas are not only characterised by different micro-climates but also govern erosion and deposition events along drainage pathways (van Noordwijk et al. 1997; Koomson et al. 2020). Positioning of different land uses at upper or lower end of the catena or in convex or concave sites and their slope thus greatly influences the development of SOC stocks at a particular site and hence may confuse/invalidate direct land use comparisons. Pedo-climatic information can be included as a covariate in the statistical analysis, or taken into account via a pedotransfer function to better disentangle effects related to pedoclimatic characteristics or land use (van Noordwijk et al. 1997; Hairiah et al. 2020) to further support a more rigorous analysis (Laub et al. 2018; Lamichhane et al. 2019).

Study site history

Study site history is, if at all, often only rudimentary reported but it plays a crucial role in analysing changing SOC stocks in agroforestry systems, especially when comparing to non-agroforestry systems. This is because: (1) agroforestry plots need to be relatively large to be representative considering species diversity, planting distances, roots extension, etc.; (2) long-term temporal series of agroforestry systems exist rarely in randomized designed trials, instead are regularly assessed in chronosequences; (3) historically, different land uses have been deliberately established in specific locations within a landscape (i.e., forest rather on steep slopes, crop fields on more fertile lands). Thus, land use comparisons often include sites across a landscape or region. Apart from considering issues of pedo-climatic conditions in the design of such comparisons (see above), historical management of the study sites (including chronosequences) may also vary greatly among sites for various reasons. It is well known that SOC stocks vary greatly among arable, grassland, peatland and forest sites, and additionally inputs of organic residues (e.g., crop residues), fertilizer, compost or manure further impact initial SOC stocks, as well as their lability, if agroforestry systems are subsequently implemented on them. *It is thus essential that historical management is well documented in such studies*. Ideally, SOC stocks should be determined at the beginning of systems implementation. However, in false time series design this data is often not available. Hence, at least the corresponding data of a historically managed neighbouring site should be given. Information on adjacent land management practices is also helpful in characterizing the landscape.

Agroforestry design and management practices

Agroforestry systems are characterized by their large diversity (Nair 1993), and it is not always easy to classify them. But agroforestry system classification is very useful for instance when using emission default values (Cardinael et al. 2018a) or when synthetizing the effect of these systems on processes, e.g., soil erosion (Zhu et al. 2020). It is therefore crucial for authors to provide a clear description of the system. A photo or diagram can be included as supplementary information. When possible, the *age of the agroforestry system* should be provided, it is compulsory if carbon accumulation rates in soils or biomass are presented. If the system includes several *tree rotations, their duration and number* should be provided as well.

All studies on carbon, either biomass or soil, in agroforestry systems must provide this basic set of information: *total tree density* (number of trees per hectare), *tree species (using common names and Latin names)* and *abundance of each tree species.* Other management practices including initial planting density, thinning, and current tree density must also be provided. The *design* of the agroforestry plot must also be provided. For example: are the trees scattered (random) or aligned (systematic)? If trees are aligned, what distance between two tree rows and between two trees in a given row (i.e., distance within and between tree rows)? Were the trees derived from natural regeneration or planted?

Finally, the *management of the trees and of the crops or livestock* must be clearly detailed. Are the trees pruned, and how severely and frequently? Are pruning residues exported or left on the plot? If they are left on the plot, it is useful if the amounts returned can be quantified as this relates very closely to topsoil SOC. Is there natural or sown herbaceous vegetation under the trees, and how is it managed? What are the crops and how are they managed (e.g., are crop residues returned to the soil)? Is the soil cultivated, if so what type of cultivation i.e., mouldboard plough, disc plough, etc.? Are trees and/or crops fertilized with organic and/or mineral fertilizers? If yes, what type, amount, frequency? What type of livestock, stocking rate and grazing system (continuous, rotational etc.) is applied? In summary, any information that clearly describes the management of the agroforestry system must be included and clearly explained.

Basic definitions related to carbon studies

Many studies still mix up ‘carbon content’, ‘carbon stock’, ‘carbon accumulation’ or ‘carbon sequestration’. Carbon content or concentration of biomass and soil is often expressed in percent (%), but following international units it should be in g C kg^{-1}. A stock represents an amount of carbon usually per unit of area, for instance Mg C ha^{-1} or kg C m^{-2}, and in case of SOC to a defined soil depth. It can also be expressed per individual tree in the case of biomass, for instance kg C $tree^{-1}$, and sometimes per unit of length, for instance in the case of hedgerows (Mg C km^{-1}). Carbon sequestration involves a time factor, it is a rate process, and the age of the system is needed to calculate this rate. The unit is then Mg C ha^{-1} yr^{-1}.

Requirements for reporting carbon in biomass

Using the right allometric equations

The most accurate estimations of biomass usually involve destructive sampling, however, this method is seldom used in agroforestry research since it would involve cutting of trees in farmers fields. Aboveground biomass is therefore usually estimated using allometric equations involving measurements of diameter at breast height (DBH) and/or tree height (Fig. 1a) and sometimes wood density. *DBH data should be presented by the authors. Total basal area of each tree species and tree height is highly recommended too.* A few recent studies also use innovative techniques, such as LiDAR to estimate aboveground biomass (Berge et al. 2021). Root biomass sampling of trees is even less frequently done, and reliable estimates are difficult to obtain because of the large heterogeneity and deep roots. New techniques, such as ground-penetrating radar, offer new perspectives, but many challenges remain (Borden et al. 2014). Thus, root biomass is mostly estimated based on assumed root:shoot ratios, but the uncertainty is huge. However, authors must keep in mind that most of these allometric equations,

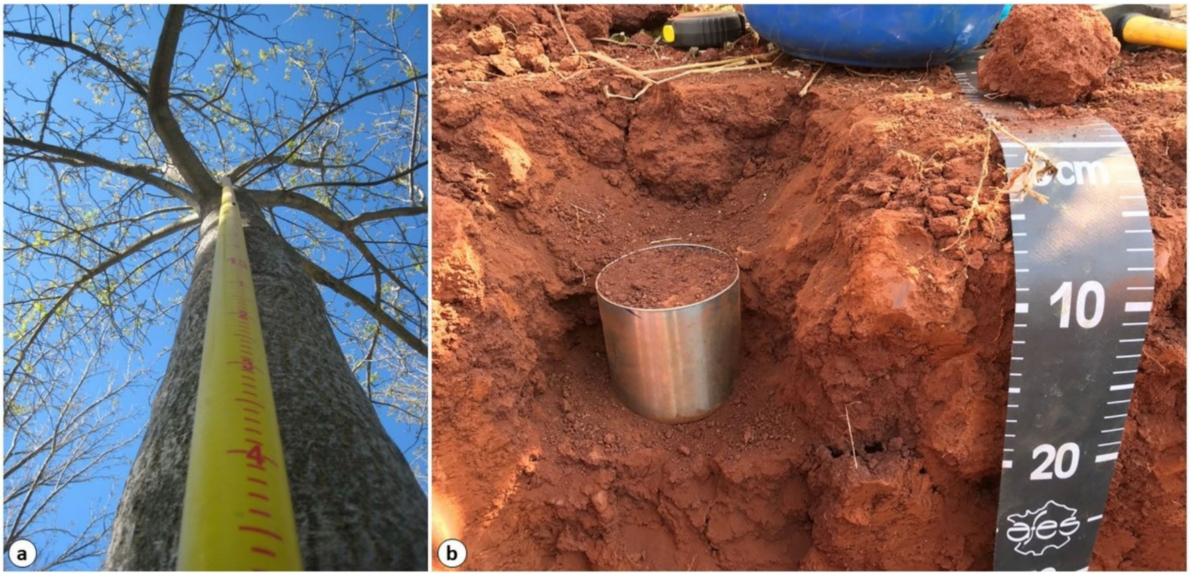

Fig. 1 Examples of two common field-based data acquisition methods in carbon studies under agroforestry systems. **a** Tree height measurement. **b** Soil bulk density sampling using the cylinder method. ©Rémi Cardinael

with a few exceptions (Kuyah et al. 2012), have been developed in forest ecosystems. Because of the lower density of trees in agroforestry systems compared to a forest, intra- and interspecific competition between trees is reduced. The wind load on trees is also much higher in agroforestry stands, resulting in squatter trees (larger DBH for the same tree height) (Coutand et al. 2008). Agroforestry trees also benefit from agricultural inputs including fertilizers, manure, addition of tree prunings as mulch, and they usually grow faster than trees in forests (Balandier and Dupraz 1999). While some agroforestry systems are grazed by livestock and the trees themselves serve as fodder banks, in other agroforestry systems the trees are pruned regularly and the pruned biomass is returned to the soil as a source of organic matter and nutrients. All of these agroforestry system management practices change tree structure (architecture) compared to the same tree species growing in a forest. It is therefore crucial that studies report the *source of the allometric equations that are used and the context in which they were developed in addition to a statement on the limitations of using those allometric equations*. Where available, species specific allometric equations should be used rather than general ones.

Assuming sensible biomass carbon concentration

Many studies still assume that the carbon concentration of the wood represents 50% of the biomass. This amount not only varies among tree species but within tree species due to site specific factors and within the tree itself. For example, lignified components typically have a lower carbon content than non-lignified components. *If possible, we recommend the measurement of the biomass carbon concentration, using the Dumas dry combustion method* (FAO 2020). If this is not possible, refined default values based on the region (i.e., tropical, temperate, etc.) and/or the type of trees (conifer/deciduous) that have been developed should be used (Thomas and Martin 2012; IPCC 2019b). Species-specific data for biomass carbon concentration but also for wood density can also be found in the TRY global database of plant traits (Kattge et al. 2011).

Time averaged biomass and carbon estimations

Tree biomass C stocks in tree plantations (eucalyptus, rubber, oil palm, cacao, etc.) are increasing in time owing to the development from tree seedlings to the moment when a plantation is cut down and renewed. Typical plantation cycles are about 10–35 years in the tropics, 25–200 years in temperate regions, depending on the tree type, growth conditions of trees and management. An important consideration thus is that when comparing system biomass C stocks or scale plot-level measurements of plantations with different ages up to the landscape and regional level for long-term comparisons, these dynamics have to be taken into account. In order to account for the temporal variation of C stocks in plantations, the so-called time averaged C stock (*taCs*) has to be estimated (Hairiah et al. 2011). It is an estimate of the mean C stock over the whole rotation time, from planting to timber harvesting. The simplest way to calculate the *taCs* is dividing the maximal C stock (at time of clearing) by two assuming a linear increase in biomass. If more detailed data are available, i.e., C stocks in plantations of different ages or calibrated modelled growth curves, a regression equation for biomass increase in time can be derived (Blagodatsky et al. 2016).

Requirements for reporting carbon in soil

Calculating SOC stock

Many studies still compute SOC stocks in the wrong way. Soil bulk density (g cm^{-3} or kg m^{-3}) should be quantified in all treatments, and all treatments depths simultaneously to SOC measurements (Fig. 1b). The *stone content* must be considered in the calculation, i.e., the mass proportion of the coarse fraction that is >2 mm must be accounted for, if not, SOC stocks can be largely overestimated (Poeplau et al. 2017). If there are no stones in the soil, it should be explicitly mentioned.

We recommend the measurement of the SOC concentration using the Dumas dry combustion method (FAO 2020). Use of a muffle furnace is not recommended since this method does not provide high accuracy. In any case, the method used to measure SOC concentration should be clearly explained. When relevant, e.g. in calcareous soils, removal of inorganic carbon from the total carbon content must be performed, usually via acidification of the sample with 0.5 M hydrochloric acid (e.g., Oelbermann et al. 2006) or acid fumigation (e.g., Cardinael et al. 2015a).

Using the equivalent soil mass approach

Soil bulk density is affected by the type of system and by the system's management practices. Therefore, comparing SOC stocks in agroforestry systems with a reference plot, either a cropland, grassland or intact forest, must account for a possible difference in bulk density. Unfortunately, many studies still only compare SOC stocks at fixed depth, which can lead to misleading conclusions. The reference methodology related to SOC sequestration requires the calculation of SOC stocks using the equivalent soil mass approach (ESM) (Rovira et al. 2022; Raffeld et al. 2024), meaning that the same mass of mineral soil can be compared between different systems. Many articles have presented this methodology (Ellert and Bettany 1995; Ellert et al. 2002; Gifford and Roderick 2003; Lee et al. 2009; Wuest 2009; Lee and Six 2010; McBratney and Minasny 2010; Wendt and Hauser 2013). Some studies provide an Excel file (Wendt and Hauser 2013) or an R script (Ferchaud and Chlebowski 2020; von Haden et al. 2020; Fowler et al. 2023) to facilitate the calculation. To improve transparency, we ask the authors to *provide both SOC concentration and bulk density per soil layer and system* (at least in the supplementary materials) *in addition to SOC stocks expressed with the ESM*.

Different approaches and reference in space and time

Different approaches can be used to quantify the impact of agroforestry systems on SOC stocks: chronosequences, synchronic (also known as space-for-time method), or diachronic approaches (Fig. 2). The synchronic approach refers to sample collection at the same time from different (often adjacent) field plots under different land use or management systems. The diachronic approach refers to collecting samples from the same field plots over time (Bernoux et al. 2005; Leng et al. 2024). The most accurate one is the diachronic approach, but it is not often possible as it requires sampling at the time of tree planting and several years later in the same plot, ideally in the same location. The synchronic approach uses adjacent plots, one in agroforestry, and another one under another management system. This method is regularly used, but unfortunately often misused, leading to large errors. This method can only be used if crucial conditions are

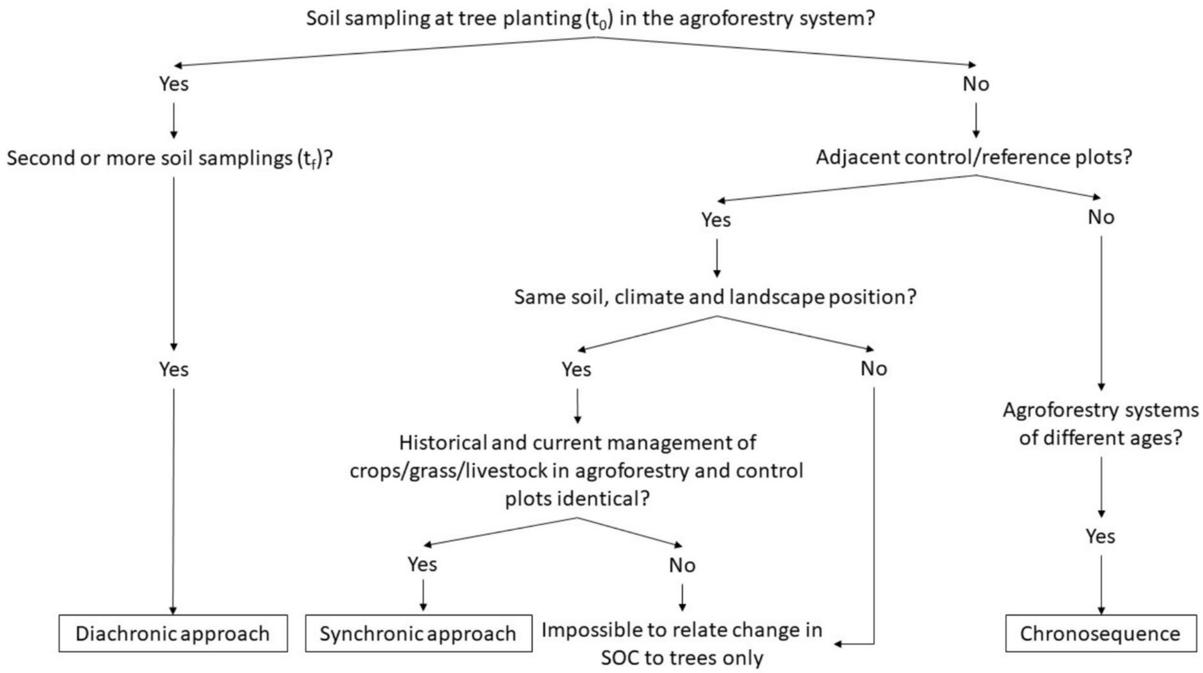

Fig. 2 Decision tree to select the appropriate approach to quantify the impact of agroforestry systems on soil organic carbon stocks

met, especially the same soil and the same previous land use and management before the implementation of the systems to be compared. If the same land uses are to be compared, for instance a silvoarable system versus a treeless cropland with the same crops, the same management of the crops after the implementation of the agroforestry system must also be guaranteed. Otherwise, any difference in SOC stocks will not only be the result of the presence of trees but of the different crop managements too. For instance, some studies compare silvoarable systems and tree-less croplands but with different management (organic inputs such as compost, etc., vs. no inputs or only mineral fertilizers). In that case, differences in SOC stocks cannot be attributed to the trees only. This is why it is crucial to clearly describe all the compared systems. If the objective is to quantify the effect of trees on SOC stocks using the synchronic approach, an appropriate *reference or control plot is needed* to assess additional SOC storage, but also the impact on climate change mitigation (Terasaki Hart et al. 2023).

Controlling soil spatial heterogeneity

Agroforestry systems are spatially heterogeneous systems and this *spatial heterogeneity must be accounted* for in the sampling design to assess the impact on SOC stocks (Bayala et al. 2006; Bambrick et al. 2010; Cardinael et al. 2015a, 2019). There is currently no standard methodology, but the sampling design can for instance include transects across the tree lines, circles around the individual trees, etc., and the sampling design should depend on the system (Minarsch et al. 2024). Many studies still only sample soil directly under the tree canopies and extrapolate additional SOC stocks to the whole plot, leading to large overestimations. On the contrary, a few studies only sample in the alley between the tree rows, which can lead to an underestimation of SOC stocks at the system level (Minarsch et al. 2024).

Sampling to a sufficient soil depth

The IPCC recommends to sample soils to at least a 30 cm depth, but most studies do not even follow this guideline, focusing on the top 20 cm (plough layer or topsoil). This sampling depth is probably not sufficient for evaluating carbon in agroforestry systems since tree roots grow much beyond this depth (Mulia and Dupraz 2006; Cardinael et al. 2015b, 2018b; Siegwart et al. 2023) and therefore have an impact on deeper soil layers (Haile et al. 2010; Upson and Burgess 2013; Cardinael et al. 2015a; Shi et al. 2018). *We therefore encourage a sampling depth of at least* 30 cm *(if soil conditions allow for this depth) and encourage the authors to sample deeper. A further consideration is the use of realistic depth increments.* Depth increments that cover a large depth e.g., 0–30 cm will be unable to detect short-term changes. *It is recommended that the* 0–30 cm *is analyzed for SOC and bulk density into several continuous soil layers, e.g.,* 0–10, 10–20, 20–30 cm *or at least to* 0–10 and 10–30 cm.

How to deal with replication vs pseudoreplications

Agroforestry systems are often large-scale systems that are not easy to study with statistical block designs and replications. Even if a large area is available allowing a robust block design, the risk that soil heterogeneity will blur the results is high, as soil homogeneity can usually only be assessed on small plots, even if new geotechnical methods can help identify and stratify for differences within fields prior to establishing trees. Most studies simply compare an agroforestry plot and a control plot. Pseudoreplications are then used to document the intra-system variability. Such a design will not allow to draw very solid conclusions that can be extrapolated to the studied system (except in diachronic studies), but pseudoreplications can and should be accounted for in statistical models such as linear mixed effect models. Strong claims cannot be the results of experiments with only intra-system pseudoreplications and synchronic or chronosequence (with very few plots) approaches, and this should be acknowledged and discussed by the authors of such studies. However, this should not deter the authors of such studies. These data are still valuable for instance for meta-analyses that will use a network of paired-sites experiments to generate more general assertions. Undue extrapolation of the results (such as a title stating boldly that “Agroforestry stores carbon”) when the experimental evidence is only from synchronic approach and pseudoreplicates in a single study site with a single agroforestry system should be avoided.

Frequency and timing of sampling

We strongly recommend collecting soil samples at time 0, i.e. before tree planting, even if no budget is available at that time for SOC analysis. Soil samples can be air dried, and analyzed later. This will enable to move towards diachronic studies and improve the quantification of additional carbon storage in soils by avoiding confounding effects. If no samples were collected at time 0, but at two other sampling dates, for example at year 3 and year 10, the diachronic approach can be used between these two sampling dates. It usually takes several years, often 5–10 years before a significant change in SOC stock can be detected (Smith 2004). Earlier changes can however be detected in soil fractions or other soil parameters. SOC stocks can slightly fluctuate between seasons (e.g. dry vs wet season), or between key management events (e.g. harvest, etc.). It is therefore crucial that in synchronic approaches soil samples are always collected at the same time in the reference plot and in the agroforestry system. In diachronic approaches, soil sampling should always happen at the same period between the different years. *Sampling dates should be indicated in the studies*.

Documentation of carbon inputs to the soil

More data is highly desirable to move from pure C stock accounting to a more process-based understanding of C dynamics. This part is most of the time missing due to the huge effort required to collect this type of data. Carbon inputs to the soil can be directly measured for the above-ground additions (litter, manure, crop residues, etc.) and estimated for instance using root:shoot ratios for the below-ground litter (root mortality). A detailed monitoring and description of tree and crop management is therefore crucial (see Sect. “Agroforestry design and management practices”). Indication of crop yields is recommended to enable estimating crop-related carbon inputs though crop residues or root biomass. An estimation of carbon inputs to the soil will allow for a better understanding of carbon dynamics in agroforestry systems, and help disentangling effects related to carbon inputs (both quantity and quality) and decomposition and stabilization processes in the soil, especially with the help of process-based models (Cardinael et al. 2018b; Laub et al. 2025). Finally, it is also useful to estimate the conversion rate of organic carbon inputs to SOC, a useful parameter to compare different systems and practices.

Conclusion: are these guidelines binding and mandatory?

These guidelines are intended to increase the quality and value of carbon sequestration studies in agroforestry systems, and to help reviewers to assess submitted manuscripts addressing these issues. Authors are strongly encouraged to follow these guidelines, and the compulsory variables must be present in articles related to this topic. We recommend that authors use the provided table to check for required data before submission, and that reviewers use this table to request missing data to authors before acceptance of articles. Methodological bias should absolutely be avoided, as they will systematically lead to the rejection of the papers. However, authors are free to define their own methodology, providing that they explain why and how their methodology is solid. The freedom in action for researchers is paramount, providing that the significance of the results is correctly stated. The presented guidelines should not discourage researchers to carry out carbon focussed studies in agroforestry systems, but instead help them to plan and follow scientifically rigorous methodology, in order to avoid future disillusion of not being able to publish the results of those studies.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The first author and the co-authors are members of the editorial board of the Agroforestry Systems journal. The peer-review process was guided by an independent editor, and the authors also have no other competing interests to declare.

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