Journal of Environmental Management 339 (2023) 117893

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Short communication

Carbon farming: Climate change mitigation via non-permanent carbon sinks

Jens Leifeld

Agroscope, Climate and Agriculture Group, Reckenholzstrasse 191, CH-8046, Zurich, Switzerland

ARTICLE INFO

Keywords:
Nature based solution
Carbon certification
Sequestration

ABSTRACT

The role of carbon farming in agriculture or forestry to mitigate climate change is currently under intensive scientific discussion along with the gradual but progressing evolution of the voluntary carbon market and its certification. An overarching issue is the question of the permanence of terrestrial carbon sinks. In this comment, I discuss the climate benefit of non-permanent carbon sinks in light of a recent publication stating that carbon certificates fall short of expectations for climate change mitigation because of their non-permanence. The beneficial effect of short-lived sinks is real and quantifiable, and this understanding is applicable within *ex ante* biophysical discounting, which has the potential to improve the trustworthiness of climate change mitigation via carbon farming.

1. Main text

Carbon farming refers to land use and farm practices to sequester carbon in natural sinks, such as vegetation and soil, or to abate greenhouse gas emissions from agricultural production (Tang et al., 2019). In a narrower sense, carbon farming can be defined as the intentional increase of carbon storage in ecosystems for the purpose of reducing the atmospheric carbon dioxide (CO_2) content. Carbon farming is increasingly seen as a way to contribute to climate change mitigation (EC, 2022). The value of carbon farming practices such as soil carbon sequestration has been acknowledged overall (Chenu et al., 2019) and has led to the evolution of so-called carbon markets, where carbon certificates, generated by means of carbon farming, are sold to compensate for greenhouse gas (GHG) emissions (Black et al., 2022). There are, however, several barriers to implementing carbon farming schemes in a scientific and reliable way, of which quantification, leakage and permanence are most important (FAO, 2020). These requirements are therefore part of evolving monitoring, reporting and verification schemes (Smith et al., 2020), which report to an accredited party that issues certified carbon credits.

The requirement of permanence in a strict sense is seen as a major obstacle to implementing carbon farming because it cannot be guaranteed. Ecosystems are open, with bidirectional fluxes of carbon (and other GHGs) that are intrinsic to any of these systems. To overcome this limitation, carbon farming schemes usually limit the requirement of ‘permanence’ to a few decades and credit savings relative to a baseline scenario (Oldfield et al., 2022). In addition, credit buffers are generated in order to compensate for possible project failures (VCS, 2019). These practices are highly disputed in the scientific community based on the argument that if the carbon content of a sink (e.g., soil) created through a project converts back to its previous level, no climate benefit is achieved. Paul et al. (2023) argued that soil carbon certificates fall short of expectations for climate change mitigation as the permanence of soil organic carbon sequestration cannot be guaranteed. Furthermore, to provide climate change mitigation and offset emissions, CO_2 removal from the atmosphere must be permanent (Paul et al., 2023). This perception is, however, misleading as temporary carbon sinks are still beneficial for the climate, even if fully reversed, as exemplified below.

The atmospheric response to a temporary (or permanent) withdrawal or release of CO_2 by a sink or a source can be quantified by using so-called impulse response functions, which represent the dynamics of atmospheric CO_2 as pools or reservoirs with varying lifespans (Joos et al., 2013; Millar et al., 2017; Smith et al., 2018; Parisa et al., 2022). The climate benefit of a temporary sink is illustrated in Fig. 1 and has been explored recently in more detail by Sierra et al. (2021) and Leifeld and Keel (2022). Fig. 1 displays the result of simulating a short-lived carbon sink (lifespan of 10 years, built-up and release period of 10 years) on the atmosphere over 1000 years. The average atmospheric CO_2 content was computed starting from t0. Whatever the integrated time horizon is, the average CO_2 with sink relative to that without sink is below zero at any point in time. In other words, a short-lived sink has a very long-lived and quantifiable climate benefit.

E-mail address: jens.leifeld@agroscope.admin.ch.

https://doi.org/10.1016/j.jenvman.2023.117893
Received 28 February 2023; Received in revised form 28 March 2023; Accepted 6 April 2023

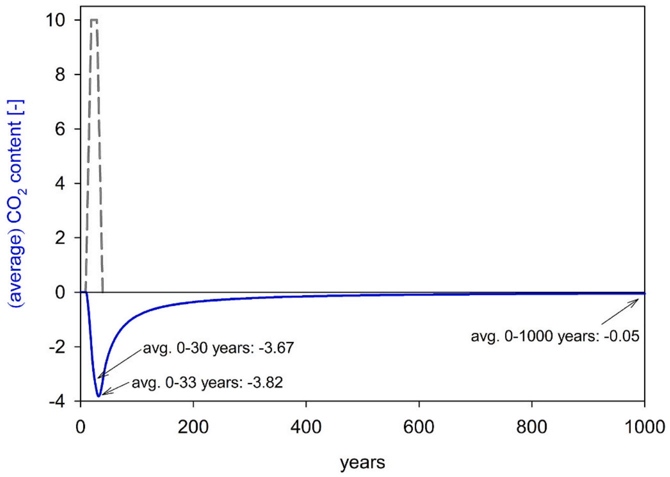

Fig. 1. A temporary terrestrial carbon gain (dashed, grey) and the corresponding response of the **average** atmospheric CO_2 content (blue). For better comparability, the sink is displayed in CO_2 units and has a positive sign. Sink formation is initiated at t = 10 years (t10), builds up to a maximum of 10 units of CO_2 at t20, holds the CO_2 for 10 years, and then loses CO_2 between t30 and t40 until reaching the pre-experimental level. The solid black line shows the reference situation. The blue line displays the **average** atmospheric CO_2 since t0. A maximum reduction is reached after 33 years with an average CO_2 depletion of −3.82 units of CO_2. The depletion before the terrestrial sink turns into a CO_2 source is −3.67 units of CO_2. The average effect on the atmospheric CO_2 content relative to the reference remains negative (−0.05 CO_2 units), even after 1000 years. For the calculations, relative fractions of atmospheric CO_2 of 0.2173, 0.224, 0.2824 and 0.2763, and perturbation lifetimes of 10ˆ6, 394.4, 36.54 and 4.304 years were used following Joos et al. (2013) and Millar et al. (2017).

The average sink size (represented by the integral under the dashed line in Fig. 1) is almost linearly proportional to the cumulative global cooling and thus average reduction in atmospheric [CO_2] (Leifeld and Keel, 2022; Sierra et al., 2021). Of course, one ton of CO_2 sequestered for a limited time period—in many protocols, requirements for permanence are only years to decades (Oldfield et al., 2022)—does not offset the long-lasting climate effect of the same amount of CO_2 emitted by, e.g., fossil fuel combustion (Leifeld and Keel, 2022). Withholding buffers are used in carbon certification in this context, but they are not biophysically substantiated, instead acting as a risk-management tool. *Ex ante* discounting or temporary crediting (Murray et al., 2007) have been proposed as suitable methods if the value of the discount rate or issued credit is aligned with the difference in atmospheric CO_2 between a shorter-lived and a permanent sink. However, this has not been detailed hitherto, and the question arises as to how the longevity of a sink of the same size relates to its climate benefit. An example of this is provided in Fig. 2.

In all calculations, the average CO_2 remains below zero throughout the simulated period. The slope of the regression line in Fig. 2 is 1.16% per year. The offset of 6.8% is caused by the 10-year build-up phase in the beginning (t10-t20). In the example, the soil sink of -10 units of CO_2 is reached after 20 years and held at maximum for 80 years. Hence, of the 100% maximum achievement, 100%–6.8% = 93.2% are obtained between t20 and t100; i.e. 1.16% × 80. The relationship is almost linear over the considered time horizon ($R^2 = 0.99$). This rate, in consequence, is a suitable *ex ante* biophysical discount relative to a sink that is considered permanent, i.e., held for 80 years after reaching the maximum sink size of 10 units of CO_2 at t20 in this example. Instead of paying an advanced payment, a project developer or offset broker may therefore reward the farmer who generated the sink in the form of an annual interest rate of, in this example, 1.16%. This annual payment would be discontinued in the event of sink reversal. Such a scheme would have two advantages – the climate benefit achieved by any point of discontinuation is fairly remunerated, and continuation of the project is encouraged.

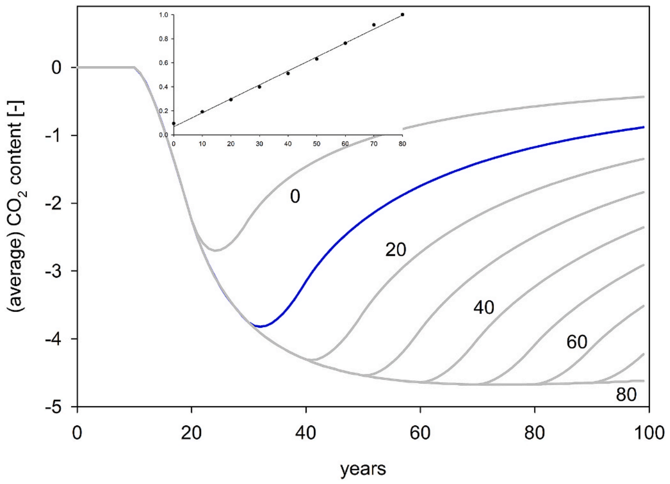

Fig. 2. Average atmospheric CO_2 content over 100 years following a soil carbon sink implemented for different durations relative to a sink maintained for 80 years. The sink is built up to a maximum of 10 units of CO_2 starting at t10 at an annual rate of one unit of CO_2 per year. Starting at t20, the CO_2 is held for different periods, as indicated by the numbers beside the lines. The blue line represents the same scenario as in Fig. 1. The small insert shows the average atmospheric [CO_2] at t100 of the shorter lived sinks relative to maintaining the sink until t100.

The situation of a non-permanent sink must not be confused with and is quite different when investigating temporarily avoided emissions, as illustrated in Fig. 3. Here, a displaced emission, for example, payments for avoiding clearcutting a forest for 40 years (from t10 to t50 in this example), will in the long run have the exact same effect on the atmospheric CO_2, with the difference diminishing and becoming zero once the atmospheric perturbation has faded out. However, the integral under the curve – sometimes referred to as the 'ton-year' (Moura Costa and Wilson, 2000) – differs when using a shortened time horizon, such as 100 years, which is considered 'permanent' in carbon certification schemes (VCS, 2019). The corresponding integrals are 485.1 and 305.3 ton-years for clearcutting a forest at t10 and t50, respectively, resulting in an emission 'saving' of 179.8 ton-years. Hence, only owing to the

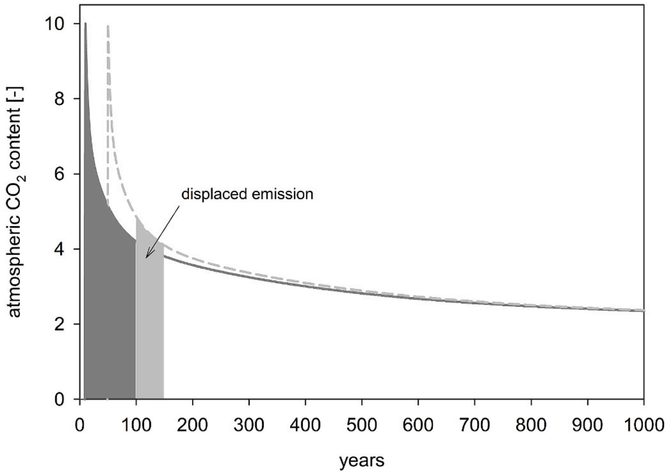

Fig. 3. Time-course of atmospheric CO_2 following a pulse emission induced by clearcutting a forest at t10 (solid dark grey line) and t50 (dashed light grey line), instantaneously releasing 10 units of CO_2 into the atmosphere. The dark grey area integrates over one century (t0–t100) for the 10-year example. The light grey area represents the emission displaced beyond the 100-year time horizon of 'permanence' for the 50-year scenario.

selection of an (arbitrary) and comparably short project duration and monitoring period, a displaced emission seemingly contributes to climate change mitigation. This fact has been identified already in earlier studies and might be one reason why carbon farming is viewed negatively. For a deeper discussion on ton-years and displaced emissions, see Fearnside et al. (2000); Levasseur et al. (2012) or Parisa et al. (2022).

In summary, a critical analysis of carbon sink certification as a means to mitigate climate change, as elaborated by Paul et al. (2023), is a valuable contribution to address the sometimes overly optimistic potential attributed to carbon farming. However, with respect to the issue of failing a permanence requirement, often seen as one important component of carbon markets, such a reservation is not justified *per se*. This is in contrast to a mere time shift of emissions, which has no net climate benefit but just allows for ‘buying time’ (Bellassen and Luyssaert, 2014). The approach proposed in this study for dealing with non-permanence by using biophysical discounting would help to improve the scientific rigor of carbon farming in terms of its wider application.

Credit author statement

Jens Leifeld: Conceptualization, Methodology, Writing.

Declaration of competing interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

Bellassen, V., Luyssaert, S., 2014. Carbon sequestration: managing forests in uncertain times. Nature 506, 153–155.

Black, H.I.J., Reed, M.S., Kendall, H., Parkhurst, R., Cannon, N., Chapman, P.J., Orman, M., Phelps, J., Rudman, H., Whalley, S., Yeluripati, J., Ziv, G., 2022. What makes an operational farm soil carbon code? Insights from a global comparison of existing soil carbon codes using a structured analytical framework. Carbon Manag. 13, 554–580.

Chenu, C., Angers, D.A., Barré, P., Derrien, D., Arrouays, D., Balesdent, J., 2019. Increasing organic stocks in agricultural soils: knowledge gaps and potential innovations. Soil Tillage Res. 188, 41–52.

EC, 2022. Proposal for a Regulation of the European Parliament and of the Council Establishing a Union Certification Framework for Carbon Removals. 2022/0394 (COD). European Commission, Brussels.

FAO, 2020. A Protocol for Measurement, Monitoring, Reporting and Verification of Soil Organic Carbon in Agricultural Landscapes. GSOC-MRV Protocol, Rome.

Fearnside, P.M., Lashof, D.A., Moura-Costa, P., 2000. Accounting for time in mitigating global warming through land-use change and forestry. Mitig. Adapt. Strategies Glob. Change 5, 239–270.

Joos, F., Roth, R., Fuglestvedt, J.S., Peters, G.P., Enting, I.G., von Bloh, W., Brovkin, V., Burke, E.J., Eby, M., Edwards, N.R., Friedrich, T., Frölicher, T.L., Halloran, P.R., Holden, P.B., Jones, C., Kleinen, T., Mackenzie, F.T., Matsumoto, K., Meinshausen, M., Plattner, G.K., Reisinger, A., Segschneider, J., Shaffer, G., Steinacher, M., Strassmann, K., Tanaka, K., Timmermann, A., Weaver, A.J., 2013. Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis. Atmos. Chem. Phys. 13, 2793–2825.

Leifeld, J., Keel, S.G., 2022. Quantifying negative radiative forcing of non-permanent and permanent soil carbon sinks. Geoderma 423, 115971.

Levasseur, A., Brandão, M., Lesage, P., Margni, M., Pennington, D., Clift, R., Samson, R., 2012. Valuing temporary carbon storage. Nat. Clim. Change 2, 6–8.

Millar, R.J., Nicholls, Z.R., Friedlingstein, P., Allen, M.R., 2017. A modified impulse-response representation of the global near-surface air temperature and atmospheric concentration response to carbon dioxide emissions. Atmos. Chem. Phys. 17, 7213–7228.

Moura Costa, P., Wilson, C., 2000. An equivalence factor between CO2 avoidedemissions and sequestration – description andapplications in forestry. Mitig. Adapt. Strategies Glob. Change 5, 51–60.

Murray, B.C., Sohngen, B., Ross, M.T., 2007. Economic consequences of consideration of permanence, leakage and additionality for soil carbon sequestration projects. Climatic Change 80, 127–143.

Oldfield, E.E., Eagle, A.J., Rubin, R.L., Rudek, J., Sanderman, J., Gordon, D.R., 2022. Crediting agricultural soil carbon sequestration. Science 375, 1222–1225.

Parisa, Z., Marland, E., Sohngen, B., Marland, G., Jenkins, J., 2022. The time value of carbon storage. For. Pol. Econ. 144, 102840.

Paul, C., Bartkowski, B., Dönmez, C., Don, A., Mayer, S., Steffens, M., Weigl, S., Wiesmeier, M., Wolf, A., Helming, K., 2023. Carbon farming: are soil carbon certificates a suitable tool for climate change mitigation? J. Environ. Manag. 330, 117142.

Sierra, C.A., Crow, S.E., Heimann, M., Metzler, H., Schulze, E.D., 2021. The climate benefit of carbon sequestration. Biogeosciences 18, 1029–1048.

Smith, C.J., Forster, P.M., Allen, M., Leach, N., Millar, R.J., Passerello, G.A., Regayre, L. A., 2018. FAIR v1.3: a simple emissions-based impulse response and carbon cycle model. Geosci. Model Dev. (GMD) 11, 2273–2297.

Smith, P., Soussana, J.-F., Angers, D., Schipper, L., Chenu, C., Rasse, D.P., Batjes, N.H., van Egmond, F., McNeill, S., Kuhnert, M., Arias-Navarro, C., Olesen, J.E., Chirinda, N., Fornara, D., Wollenberg, E., Álvaro-Fuentes, J., Sanz-Cobena, A., Klumpp, K., 2020. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biol. 26, 219–241.

Tang, K., He, C., Ma, C., Wang, D., 2019. Does carbon farming provide a cost-effective option to mitigate GHG emissions? Evidence from China. Aust. J. Agric. Resour. Econ. 63, 575–592.

VCS, 2019. AFOLU Non-permanence Risk Tool v4.0. Verified Carbon Standard.