Active Conservation and Sustainable Management on U.S. Forestlands

DESCRIPTION OF SOIL ORGANIC CARBON LOSS RATES

VERSION 1.0

2023-11-28

INTRODUCTION

This supplemental document to the ACR Methodology *Active Conservation and Sustainable Management on U.S. Forestlands*, developed by ACR and Green Assets, describes and justifies the methods to model soil organic carbon (SOC) losses used therein.

This methodology defines methods for quantifying the carbon benefits from conservation of forestland in avoidance of other land uses. The avoided (without-project, or baseline) land uses eligible for this methodology include agriculture, mining, and commercial, residential, and recreational development.

Projects which avoid conversion to agricultural land use are eligible for the quantification of emission reductions from the SOC pool. Agricultural baseline land use was exclusively chosen because the scientific literature on SOC loss from this conversion scenario is particularly robust, showing significant SOC loss within the ACR Minimum Project Term. In this methodology, emissions from the SOC pool are quantified following one of two trajectories, depending on soil order and resulting classification as either organic soil or mineral soil. The following section describes and justifies the separation of these soil types, followed by explanations for each soil class's SOC loss trajectory.

DISTINCTION OF MINERAL AND ORGANIC SOILS

Relative to their mineral counterparts, organic soils yield both a higher SOC content and higher emissions when disturbed by agricultural activities (Dessureault-Rompré et al 2020; Mikhailova et al 2019; Chimner et al 2016; Tubiello et al 2016; Kimble et al 2002). Their high fertility makes them especially susceptible to conversion to agriculture (Qiu et al 2021; Tubiello et al 2016). Increased sunlight and soil temperatures from overstory removal expedites subsidence and CO_2 emissions in converted forested wetlands (Taggart et al 2011; Kimble et al 2002).

Hydric soils can be either mineral or organic, and are formed under conditions of saturation, flooding, or ponding of sufficient duration during the growing season to cause anaerobic conditions in their upper parts (Federal Register 1994). Organic hydric soils are classified as Histosols; they are formed primarily from plant matter deposition and have comparatively high carbon contents. Histosols must have an organic layer of at least 40 cm and must have 12-18% organic carbon content (20-30% organic matter) depending on clay content (Mobilian & Craft 2021). Hydric soils that do not meet these criteria are considered mineral soils.

As such, organic soils are defined in the methodology as Histosols and all other soils having a Hydric Criterion code (Natural Resource Conservation Service 2012) of 1 (i.e., organic soils include, within the order of Histosols, all suborders other than Folists and, within the order of Gelisols, only the members of the suborder Histels other than the great group of Folistels).

MINERAL SOILS AFTER CONVERSION

To determine the effect of forest conversion to agriculture upon mineral SOC stocks we developed a SOC regression curve based on raw data from Wei et al. 2014. The Wei et al. 2014 study is the most recent and robust meta-analysis currently available containing observations of SOC loss in response to agricultural conversion, providing a sample of 453 paired or chronological sites (from 119 peer-reviewed publications across 36 countries) converted from forest to agriculture. Raw data for this study is available in its supplementary materials.[1]

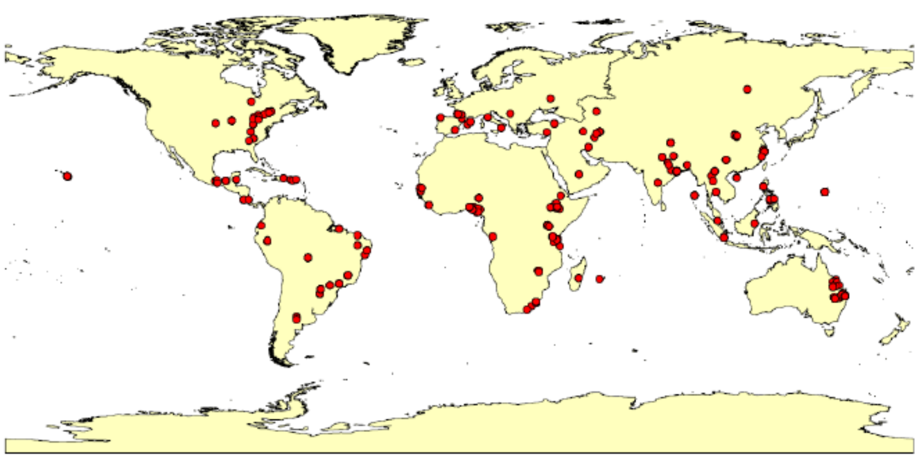


Figure 1 | Distribution of the study sites in which forests have been converted to agricultural land (created in ArcGis 10.0).

[1] https://www.nature.com/articles/srep04062#Sec9

In the study, SOC significantly decreased across 90% of the sites sampled. The decrease averaged 43% across all sites and 52% in temperate regions. The study measured SOC changes within the topsoil (0-30 cm), conforming with the sampling depth used in this methodology. Constraining SOC accounting to the top 30 centimeters is conservative because deeper sampling could increase SOC projected losses. However, management activities rarely affect SOC concentration beyond the first thirty centimeters (30 cm) of soil depth (Franzluebbers 2021).

The authors observed that forest type (temperate, tropical, boreal) and cultivation stage (<10 year, 11-50 year, >50 year) significantly affect percent decrease in SOC, with stocks decreasing the least in boreal regions and the most in temperate regions, and stocks decreasing over time (Figure 3, Wei et al. 2014). Soil clay content, bulk density, initial SOC concentration, and initial nitrogen (N) concentrations were all significantly correlated with percent decrease in SOC, but soil clay content and bulk density were negatively correlated while initial SOC and N concentrations were positively correlated (Figure 4, Wei et al. 2014).

CALCULATING SOC LOSS IN MINERAL SOILS

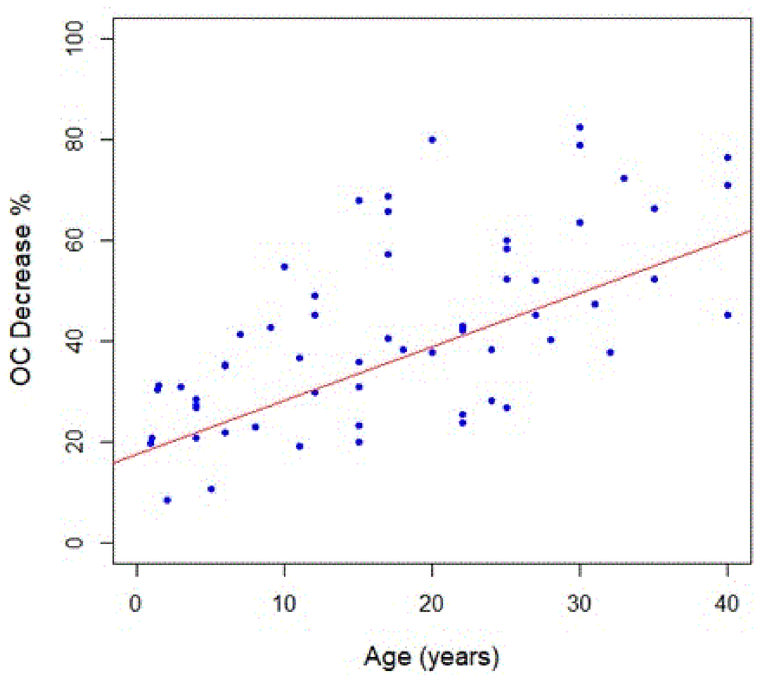
This methodology leverages the Wei et al. raw dataset, constrained to only include observations of less than or equal to 40 years since conversion in the temperate region, which aligns with the ACR Minimum Project Term and this methodology's Crediting Period length (no SOC crediting is generated in subsequent Crediting Periods) and geography. This results in an initial 338 eligible studies from which to develop a mineral SOC loss trajectory (61 temperate, 272 tropical, 5 boreal). We further constrained the dataset and performed a series of statistical analyses to develop a mineral SOC loss regression curve as outlined in Table 1 below.

Table 1: Steps to develop a mineral SOC loss regression curve

STEP	BACKGROUND AND ANALYSIS	RESULT AND IMPLICATION
1	We first examined the general data distribution and developed a scatterplot of SOC loss (%) as a function of time since conversion.	The dataset was normally distributed, with a trend of increasing SOC loss (%) over time.
2	We then examined the contribution of forest type and soil texture upon SOC loss (%) with analysis of variance (ANOVA). We assessed the individual and interactive effects of forest type, soil texture, and time since conversion upon SOC loss.	Forest type ($p < 0.01$) and time since conversion ($p < 0.001$) significantly affected SOC loss. Soil texture did not significantly affect SOC loss ($P = 0.17$). There were no significant ($p > 0.05$) interactive effects of forest type, soil texture, and time since conversion upon SOC loss.

STEP	BACKGROUND AND ANALYSIS	RESULT AND IMPLICATION
		Due to the significant effect of forest type, we subsequently constrained the dataset to the "temperate" forest type only, reducing the dataset to 61 observations. This forest type is most appropriate for the methodology's geographic scope, which is constrained to the United States of America.
3	Using the newly constrained temperate forest dataset, we examined the effect of sampling depth in relation to SOC loss (%) over time. To do so, we developed an ANOVA that included sampling depth, time since conversion, and their interactive effects upon SOC loss (%).	Sampling depth was not a predictor of SOC loss ($p = 0.49$) and the interaction between sampling depth and time since conversion was not significant ($p = 0.65$). Again, time since conversion was a significant predictor of SOC loss ($p < 0.001$). Sampling depth was subsequently excluded from the model and time since conversion alone can be used as a predictor of SOC loss.
4	The final dataset, including 60 temperate forest site observations (after excluding one outlier), was examined with a linear regression model. The model predicts SOC loss as a function of time since conversion.	The temperate forest model is a significant predictor of SOC loss over time (R2 = 0.41; $p < 0.001$). The average rate of change derived from the model is a decrease of 1.06% per year for a 40-year timeframe. For conservatism, we use the lower bound of the 90% confidence threshold, which decreases the intercept estimate from 23.48 to 17.68. Our final model predicts significant loss of SOC year over year when forest is converted to agriculture. The final regression equation is $y = 17.68 + 1.06(x)$. The model credits 60.08% SOC loss from initial SOC stocks over the 40-year Minimum Project Term.

Figure 1: SOC decrease as a simple linear function of time since conversion from temperate forest to agriculture, using the lower 90% Confidence Interval as the intercept



The proposed equation for projecting mineral SOC stocks as affected by conversion from forest to agriculture over a 40-year time period, found in the methodology as Equation 41, is as follows:

Equation 41: Baseline SOC Mineral Stocks

$$C_{BSL,SOC,MNL,t} = SOC_{MNL,0} \times (1 - [17.68\% + (t \times 1.06\%)])$$

WHERE

t	Time in years (since project Start Date).
$C_{BSL,SOC,MNL,t}$	Baseline SOC stock in mineral soils (in metric tons CO_2) at the end of year **t**.
$SOC_{MNL,0}$	Initial SOC stock in mineral soils (in metric tons CO_2) (**t**=0).

ORGANIC SOILS AFTER CONVERSION

Forested organic soils (as defined in the methodology) lose SOC after conversion to agriculture through two mechanisms: emissions from geophysical processes (e.g., wind/water erosion and sedimentation, compaction) caused by conversion (primary subsidence), and emissions by microorganisms as part of oxidative subsidence (secondary subsidence) (Gesch et al. 2007; Ewing & Vepraskas 2006; Kimble et al. 2002). Removal of carbon through conversion to annual crop systems exacerbates the carbon loss in these systems (Dessureault-Rompré et al. 2020; Gesch et al. 2007; Klemedtsson et al. 1997).

The emissions resulting from these processes vary widely (Dessureault-Rompré et al. 2020; Liefeld et al. 2011; Klemedtsson et al. 1997) and from site to site (Liefeld et al. 2011; Murty et al. 2002). Klemedtsson et al. (1997) found that farmed organic soils are large emitters of CO_2, ranging from 8 – 115 t CO_2/ha/yr. Rates of subsidence vary (Dessureault-Rompré et al. 2020; Ewing and Vepraskas 2006) and the oxidative contribution to overall subsidence varies between sites (Liefeld et al. 2011). Liefeld et al. (2011) found that oxidative subsidence contributed 28-64% of total volume loss among four study sites. Emission rates vary with land use (Murty et al. 2003; Klemedtsson et al. 1997), tillage depth, and other agricultural practices (Gesch et al. 2007). Annual SOC loss rates in drained hydric soils in temperate climates range from 2.5 tC/ha/yr. to as much as 31 tC/ha/yr. in the literature examined. Annual secondary subsidence rates vary from 0.5 cm/yr. to 2.0 cm/yr. (Dessureault-Rompré et al. 2020; Liefeld et al. 2011; Ewing and Vepraskas 2006; Klemedtsson et al. 1997).

CALCULATING SOC LOSS IN ORGANIC SOILS

After forest conversion to cultivated agriculture, there is a rapid decrease in SOC stocks in the first several years followed by a smaller rate of change in subsequent years (Murty et al. 2002). Murty et al. (2002) reviewed 75 studies in which forest was converted to agriculture and found, on average, a rapid loss of SOC within the first few years after conversion followed by gradually fewer emissions. Qui et al. (2021) also found that SOC loss decreases with time since drainage, estimating 92% fewer emissions today from a peatland drained in 1900 versus one drained in 1990.

The unique and rapid weathering processes of organic soils result in a markedly higher loss of SOC than mineral soils when converted to agriculture. Given this methodology's mineral SOC stock loss following conversion to agriculture (approximately 60% over 40 years), we propose a loss rate of 90% of the initial organic SOC stock estimate over 40 years. To account for the temporal effects noted in our literature review, the methodology distributes organic soil SOC losses according to Table 4 (as found in the methodology):

Table 4: Organic Soil Loss Schedule

YEARS POST-CONVERSION	ANNUAL LOSS RATE
1-5	9.0%
6-10	5.4%
11-40	0.6%

The methodology also allows for a more conservative option for crediting organic soil SOC losses. While this option doesn't reduce cumulative crediting, it evenly distributes crediting over the entire 40-year Minimum Project Term, effectively slowing down crediting from its expected biological distribution. This option is captured in Equation 43 in the methodology:

Equation 43: Baseline SOC Organic Stocks using Steady Decline

$$C_{BSL,SOC,ORG,t} = SOC_{ORG,0} \times [1 - (t \times 2.25\%)]$$

WHERE

t	Time in years (since project Start Date).
$C_{BSL,SOC,ORG,t}$	Baseline SOC stock in organic soils (in metric tons CO_2) at the end of year **t**.
$SOC_{ORG,0}$	Initial SOC stock in organic soils (in metric tons CO_2) (**t**=0).

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