Food and Agriculture
Organization of the
United Nations

Global Soil Organic Carbon Sequestration Potential Map

GSOCseq

Technical specifications and country guidelines

Pillar 4
Working
Group &
INSII

GLOBAL SOIL
PARTNERSHIP

Technical specifications
and country guidelines for

Global
Soil Organic Carbon
Sequestration
Potential
Map

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Food and Agriculture Organization of the United Nations

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Abbreviations

BAU – Business as usual

BIO - Microbial Biomass

C_{eq} - Estimated annual C input at equilibrium

Ct – Annual carbon inputs for a specific year

CO_2 – Carbon dioxide

CRU - Climate Research Unit, University of East Anglia

DM – Dry matter

DPM - Decomposable plant material (C pool)

GHG – Greenhouse gases

GSOCmap – Global Soil Organic Carbon Map

GSOCseq – Global Soil Organic Carbon Sequestration Potential Map

GSP - Global Soil Partnership

HUM - Humified soil organic matter (C pool)

HWSD – Harmonized World Soil Database

INSII - International Network of Soil Information Institutions

IOM - Inert organic matter (C pool)

IPCC - Intergovernmental Panel on Climate Change

ITPS – Intergovernmental Technical Panel on Soils

NDVI - Normalized difference in vegetation index

NPP - Net Primary Production

P4WG - Pillar 4 Working Group

QA/QC - Quality Assurance/Quality Check

RMSE – Root mean square error

RPM - Resistant plant material (C pool)

SOC - Soil organic carbon

SOC_{meas} - Measured soil organic carbon (as in GSOC map)

SOC_{seq} – Soil organic carbon sequestration

SOC_{sim} - Simulated soil organic carbon after the first equilibrium run

SOM – Soil organic matter

SSM - Sustainable soil management

SSM1 – Low carbon inputs sustainable soil management scenario

SSM2 - Medium carbon inputs sustainable soil management scenario

SSM3 – High carbon inputs sustainable soil management scenario

VGSSM - Voluntary Guidelines for Sustainable Soil Management

Units

cm - Centimeter

dS/m - DeciSiemens/meter

ha – Hectare

m – Meter

t – Ton

yr - Year

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INSII - International Network of Soil Information Institutions

ITPS - Intergovernmental Technical Panel on Soils

4per1000 SCT - 4 per 1000 Scientific and Technical Committee

CIRCASA - (Coordination of International Research Cooperation on Soil Carbon Sequestration in Agriculture)

UNCCD-SPI - The UNCCD Science-Policy Interface

Summary

This document provides technical specifications and guidance for the generation of national Soil Organic Carbon Sequestration Potential (GSOCseq) maps at 1km resolution for agricultural lands, based on a ‘bottom–up’, country-driven approach. SOC stocks 0 – 30 cm of mineral soils shall be projected over a 20–year period after adoption of Sustainable Soil Management (SSM) practices oriented to increase carbon inputs to cropland and grassland soils. In order to obtain consistent results and to allow comparisons between countries and regions, the use of RothC as a standard spatialized SOC model is requested. General modeling procedures, data requirements and data sources are described. The final product specifications and data submission formats are also provided. This approach will require collaboration and interaction with country–level digital mapping and modeling experts and local capacity building. GSP will organize training sessions to support countries that require technical assistance to produce their own maps, and will facilitate the production of datasets for countries lacking the required local input data. The final product will be relevant to identify which regions, environments and agricultural systems present the greater potential for increasing SOC stocks, and to establish priorities for the implementation of global and national public and private policies.

Overview: Product specifications

Overview product specifications	
Products	• Absolute average sequestration rates over 20 years (t C ha^{-1} yr^{-1}), for BAU, SSM1, SSM2 and SSM3 scenarios • Mean relative sequestration rates over 20 years (t C ha^{-1} yr^{-1}), for SSM1, SSM2 and SSM3 scenarios • Initial SOC stocks at t0 (t C ha^{-1}) • Uncertainty maps • Supplementary national maps
Depth	0–30 cm
Extent	National level raster maps (spatial resolution of 1 km or 30 Arc-Second)
Projection	WGS 84 (Decimal Degrees Geographic)
Uncertainty	Width of prediction interval at 95% confidence interval
Documentation	Metadata (Metafile)
Delivery	Online (GSP Data Submission Tool)

Approach		
Process	Compilation of field data: available local and regional studies on the effects of agricultural practices on annual C inputs and SOC sequestration rates	
	Compilation and harmonization of input data layers	
	Spatial modeling of SOC stocks and absolute and relative sequestration rates	Preliminary model test and comparison against field data
		Long Spin up/ equilibrium runs
		Short spin-up runs
		Forward runs
	Generation of national maps	
	Comparison of results against compiled field data	

Input data requirements

Data	Variables	Time series	Units	Type	Resolution
Climate data	Monthly air temperature	1980─2000; 2001─2020 (or until last year available)	°C	Raster	50 x 50 km or finer
	Monthly evapotranspiration/ pan evaporation	1980─2000; 2001─2020 (or until last year available)	mm	Raster	50 x 50 km or finer
	Monthly precipitation + irrigation	1980─2000; 2001─2020 (or until last year available)	mm	Raster	50 x 50 km or finer
Soil data	Topsoil clay content (0-30 cm)	-	%	Raster	1 x 1 km
	Current Soil organic carbon stocks (0-30 cm)	Latest version of national FAO-GSOC map	tC ha^{-1}	Raster	1 x 1 km
Land use/cover	Predominant land use/cover, re-classified into: Minimum: 3 default classes required by model: agricultural crops, grassland/shrubland/savannas and forestry Optimum: 11 classes defined in the FAO Global Land Cover - SHARE (GLC─SHARE)	Minimum: 2000 and 2020 (or last year available) Optimum: annual land use 2000 to 2020	Land Cover Classes (1─3 or 1─11)	Raster	1 x 1 km
	Monthly vegetation cover. Obtained from national statistics/local expert knowledge; or derived from NDVI or spectral indexes (see section 3.3.4)	Minimum: average 2000─2020 (or last year available) Optimum: annual land use 2000 to 2020	binary: covered/ uncovered (0─1)	Raster	1 x 1 km

1. Introduction

1.1. Background and objectives

Soils constitute the largest active terrestrial carbon (C) pool: an estimated total of 1500–2400 Pg or Gt C up to 1m (Scharlemann *et al.*, 2014; Batjes, 2016; Tifafi *et al.*, 2017). Although soils contribute a major share of agricultural greenhouse gas (GHGs) emissions, due to their large size and long residence time, even small increments of net soil C storage represent a substantial C sink potential (Paustian *et al.*, 2016; Smith *et al.*, 2020). It has been suggested that soil C sequestration through improved soil/land management practices could be a significant greenhouse gas removal strategy (Smith et al, 2008; Lal *et al.*, 2018; Smith *et al.*, 2020). However, the extent and rates of soil organic carbon (SOC) sequestration under different land use and management practices can vary greatly depending on soil characteristics, topography and climate (Smith *et al.*, 2008; Lal *et al.*, 2018; Batjes *et al.*, 2019). It is thus relevant to identify which regions, environments and agricultural systems present the greater potential for increasing SOC stocks, and to establish priorities for the implementation of public and private policies.

Coupling SOC models to GIS (Geographic Information Systems) platforms allows modeling to move from site-specific SOC stocks simulations to spatial simulations (e.g. Smith *et al.* 2005; Milne *et al.*, 2007; Kamoni *et al.*, 2007; Falloon *et al.*, 2007; Gottschalk *et al.*, 2013; Lugato *et al.*, 2014), and thus to identify conditions with greater SOC sequestration potential. However, the use of GIS-based models may be restricted by the availability of quality local data, as well as technical and computational capacity (FAO, 2019a). In this sense, GSP-FAO has established the 'Global assessment of soil organic carbon sequestration potential initiative' (GSOCseq) (FAO, 2019b) which aims to build this capacity internationally. In the first stage, a 'top-down' empirical modeling approach was implemented to estimate SOC stock changes using IPCC default Tier 1 factors. A 'bottom-up' approach, driven by countries and including local expert knowledge was proposed as a second stage, based on harmonized and best available local data and the implementation of SOC process-oriented models.

Within the framework of the GSOCseq initiative, the objectives of these technical guidelines are to:

- Outline technical specifications for country-driven mapping of SOC sequestration potential using harmonized procedures
- Guide a harmonized global SOC sequestration potential (GSOCseq) map

1.2. Global Soil Partnership

The Global Soil Partnership was established in December 2012 as a mechanism to develop a strong interactive partnership and to enhance collaboration and synergy of efforts between all stakeholders. From land users to policymakers, one of the main objectives of GSP is to improve governance and promote sustainable management of soils. Since its creation, GSP has become an important partnership platform where global soil issues are discussed and addressed by multiple stakeholders.

The mandate of GSP is to improve governance of the planet's limited soil resources in order to guarantee productive agricultural soils for a food-secure world. In addition, it supports other essential soil ecosystem services in accordance with the sovereign right of each Member State over its natural resources. In order to achieve its mandate, GSP addresses five pillars of action to be implemented in collaboration with its regional soil partnerships (Figure 1).

Figure 1 GSP Pillars of Action (Source: http://www.fao.org/global-soil-partnership/pillars-action/en/)

Pillar Four of GSP builds an enduring and authoritative global system (GloSIS) to monitor and forecast the condition of the Earth's soil resources and produce map products at the global level. The secretariat is working with an international network of soil data providers (INSII - International Network of Soil

Information Institutions) and the Pillar 4 Working Group (P4WG) to implement data related activities. INSII forms the backbone of Pillar 4 and is supported by a technical working group of soil information experts nominated by GSP Regional Soil Partnerships (P4WG). Among other tasks, this working group elaborates additional guidance for the development of soil data products, which build on existing and new national and other local soil information, and for which extracts of such data fit into the global soil information system product scheme.

1.3. Country-driven approach and tasks

The project focuses on country-driven actions. The following basic approaches for the voluntary sharing of national SOCseq maps are possible, based on the availability and capacity of the countries' data (Fig. 2):

a) For countries that already have national SOC sequestration maps:

  a.1) If the maps meet the specifications of this project, the maps may be directly shared for this global SOCseq mapping project.

  a.2) If a national SOCseq map exists, but not all requirements are met, adjustments to the existing SOCseq should be implemented if possible (e.g. recalculation considering the technical specifications in this document). Adjusted maps may be shared for this global SOCseq mapping project.

b) For countries where national SOCseq maps are not available, or existing SOCseq maps do not meet the specifications and re-calculation and adjustments are not possible:

  b.1) If countries have access to the required local input data and technical capacities to run the standard model and generate their own maps based on the specifications recommended here, the generated maps may be shared for this global SOCseq mapping project. If countries lack the input data required to run the model, countries are encouraged to mobilize resources necessary to generate the national data to produce the maps.

  b.2) If countries have the required local inputs but lack adequate technical expertise to produce and share national SOCseq maps:

  b.2.1) Training sessions will be organized to support these countries to produce and share their own maps.

  b.2.2) Alternatively, if these countries elect to authorize GSP to produce the maps on their behalf, the GSP Secretariat will arrange to facilitate data exchange and mapping. Countries may have their tile gaps filled by the GSP Secretariat in the interim until technical capacity is strengthened.

The GSP Secretariat will also develop a gap-filling strategy for countries that are unable or unwilling to provide maps and local data for the required time span (Fig. 2, pathway c)

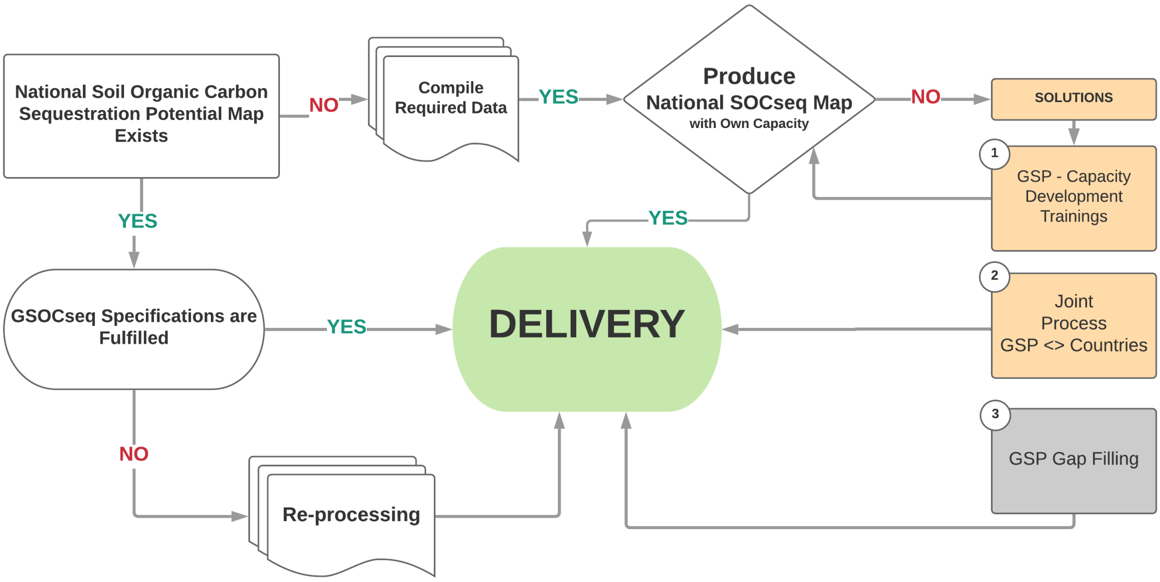

Figure 2 Production Workflow for the development of the SOCseq national maps.

2. General framework for mapping carbon sequestration potential

SOC sequestration estimates will focus on croplands and grazing lands for the current GSOCseq map version. As defined by IPCC (2006), croplands include: all annual and perennial crops (cereals, oils seeds, vegetables, root crops and forages); perennial crops (including trees and shrubs, orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas), and their combination with herbaceous crops (e.g., agroforestry); arable land which is normally used for cultivation of annual crops, but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation (mixed system), is to be included under croplands. Grazing lands include different land uses permanently dedicated to livestock production with a predominant herbaceous cover, including intensively managed permanent pastures and hay land, extensively managed grasslands and rangelands, savannahs, and shrublands.

Since the proposed standardized methodology and the defined model are neither parameterized nor recommended for use on organic, sandy, saline, and waterlogged soils, soils with SOC stocks higher than 200 t C ha^{-1}, sand contents higher than 90% and/or electrical conductivity higher than 4 dS m^{-1} at 0–30 cm depth, paddy rice lands, peatlands and wetlands will be masked out from the global results in this first version.

Excluded conditions and land uses can be included in future versions of the GSOCseq map, as harmonized procedures for specific conditions are developed. Countries are nevertheless encouraged to provide supplementary maps developed using preferred alternative SOC models and methodologies, especially for excluded conditions (see section 3 and section 4.2, optional datasets).

2.1 SOC sequestration estimates

In order to assess the SOC sequestration potential, SOC stocks in 0–30 cm of mineral soils shall be projected over a 20-year period, under business as usual land use and management, and after adoption of Sustainable Soil Management (SSM) Practices in croplands and grazing lands (See sections 2.2). A 20-year period is assumed to be the default period during which SOC stocks are approaching a new steady state, to be able to compare results among regions and countries, and with other estimation methods (e.g. IPCC, 2006 Tier 1-2; IPCC, 2019). Nevertheless, countries can project SOC stocks over 20, 50 or 100 years or more, and determine the stocks and the period at which a new steady state is attained according to local conditions, and produce additional sequestration maps (See mandatory and optional products, sections 4.1 and 4.2).

SOC sequestration can be expressed in different ways, depending on the definition of SOC baseline stocks. These guidelines will refer to two types of SOC sequestration: an 'absolute SOC sequestration' (SOCseq abs), expressed as the change in SOC stocks over time relative to a base period (or reference period, t0); and a 'relative SOC sequestration' (SOCseq rel), expressed as the change in SOC stocks over time relative to the business as usual scenario (Fig. 3). Thus, the 'absolute' attainable SOC sequestration can be determined for the business as usual and SSM practices (See section 2.2), and can be either positive, neutral or negative:

$$\Delta SOC_{ABS}\ (t\ C\ ha^{-1}) = SOC_{SSM/BAU\ t} - SOC_{t0} \quad (1)$$

where $SOC_{SSM/BAU\ t}$ refers to the final SOC stocks after a 20-year period (year 2040, under the business as usual or SSM practices), and SOC_{t0} refers to the initial or base period SOC stocks (e.g. as in year 2020). The 'relative' attainable SOC sequestration is either neutral or positive, can be determined as:

$$\Delta SOC_{R}\ (t\ C\ ha^{-1}) = SOC_{SSM\ t} - SOC_{BAU\ t} \quad (2)$$

where $SOC_{SSM\ t}$ refers to the final SOC stocks after a 20-year period of implementing SSM practices and $SOC_{BAU\ t}$ refers to the final SOC stocks after a 20-year period under business as usual (BAU) practices. Mean annual SOC sequestration rates (t C ha^{-1} yr^{-1}; absolute or relative) are to be determined by dividing SOC changes by 20 years.

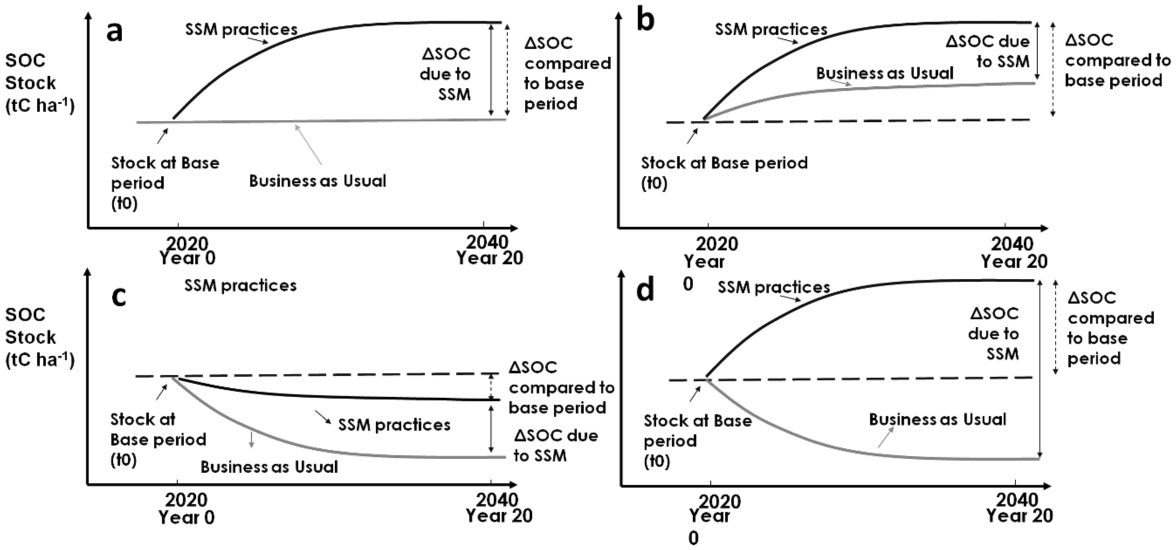

Figure 3 Theoretical evolution in Soil Organic Carbon stock under a business as usual (BAU) scenario and after adoption of sustainable soil management practices: a) lands where SOC levels have reached equilibrium and where it is possible to increase levels under SSM; b) lands where SOC is increasing but can be further increased through SSM; c and d) lands where SOC is decreasing and where it is possible to mitigate (c) or reverse (d) this fall through SSM.

2.2 Business as usual and SSM scenarios

The BAU scenario refers to the land use, land management, production practices or technologies that are currently being implemented (as in time = 0, or 2020) in croplands and grazing lands. BAU practices represent typical, prevailing practices in a specific agro-ecological zone and productive system. SSM practices refer to management practices that are expected to remove CO_2 from the atmosphere and retain it as SOC, to enhance SOC accumulation, or to mitigate or reverse SOC losses compared to the BAU (Fig. 3). Although there is no universal soil management practice, basic principles are widely applicable, such as those identified in the Voluntary Guidelines for Sustainable Soil Management (VGSSM; FAO, 2017) for enhancing soil organic matter content:

- increasing biomass production and residue returns to the soil;
- using cover crops and/or vegetated fallows;
- implementing a balanced and integrated soil fertility management scheme;
- implementing crop rotations, combining legumes and pulses with high residue crops, or improving the crop-mix;
- effectively using organic amendments, manure, or other carbon-rich wastes (which are not currently applied to soils);
- promoting agro-forestry and alley cropping;
- managing crop residues and grazing to ensure optimum soil cover; among others.

A very wide range of management practices are currently being implemented and can potentially be introduced into the world's agricultural systems, depending on climatic, soil, socio-cultural and economic conditions. In turn, different SSM C-oriented practices are often combined, making it difficult to dissociate their effects on SOC dynamics. Thus, as a first step, and to harmonize the results on a global map, and because soil carbon turnover models are the most sensitive to carbon inputs, these guidelines propose to group SSM practices into three scenarios as a standard method, based on their expected relative effects on C inputs compared to BAU: Low, Medium and High increase in C inputs (referred as SSM1, SSM2, and SSM3 scenarios; for technical procedures, refer to section 3.2). National experts' opinion and local data are essential in order to accurately estimate or validate the target areas and carbon input levels for the different SSM scenarios in forthcoming versions.

3. SOC modeling

To obtain consistent results and to allow comparisons between countries and regions, the use of a standard 'process-oriented' SOC model is requested. Countries are nevertheless encouraged to provide supplementary maps developed using alternative preferred SOC models (see section 4.2, optional datasets). The use of a multi-model ensemble approach (e.g. Riggers et al, 2019; Lehtonen *et al.*, 2020) with selected models is intended for future versions of the GSOCseq map.

For this first GSOCseq version, the Rothamsted soil organic carbon model (RothC; Coleman & Jenkinson, 1996) is proposed as the standard comparison model, because:

- It has fewer data requirements due to the relative simplicity of obtaining input data compared to other process-oriented models
- It has been applied using data from long-term experiments across several ecosystems, climate conditions, soils and land use classes;
- It has been successfully applied at national, regional and global scales; e.g. Smith *et al.* (2005), Smith *et al.* (2007), Gottschalk *et al.* (2012), Wiesmeier *et al.* (2016), Farina *et al.* (2017), Mondini *et al.* (2018), Morais *et al.*(2019);
- It (or its modified/derived version) has been used to estimate carbon dioxide emissions and removals in different national GHG inventories as a Tier 3 approach; according to the latest review by Smith *et al.* (2020): Australia (as part of the FullCam model, Japan (modified RothC), Switzerland, and UK (CARBINE, RothC).

A spatially explicit version of the RothC model (e.g. Gottschalk *et al.*, 2012; Mondini *et al.* 2018; Morais *et al.*; 2019) is required to generate national maps. An open source R version of the RothC model (embedded in the SoilR package) developed by Sierra *et al.* (2012) can be downloaded from the Max Planck Institute of Biogeochemistry site: https://www.bgc-jena.mpg.de/TEE/software/soilr/

If necessary, GSP will provide spatially explicit versions of the model under Fortran and R environments (based on the SoilR R-package by Sierra *et al.*, 2012) to countries that require it. Countries can use local adaptations of the RothC model by following the general procedures described in section 3.2 to obtain consistent results. Countries are asked to provide evidence (peer-reviewed scientific journal papers, university theses) demonstrating that the use of the modified version and changes in model parameters are appropriate for the selected agro-ecological conditions (attached in the corresponding report, Section 4).

3.1. RothC: general model description

In the Roth-C model (Coleman and Jenkinson, 1996), SOC is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments are Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM). The IOM compartment is resistant to decomposition. The structure of the model is shown in Figure 4. Incoming plant carbon is split between DPM and RPM, depending on the DPM/RPM ratio of the particular incoming plant material. All incoming plant material passes through these two compartments only once. Both DPM and RPM decompose to form CO_2, BIO and HUM. The proportion that goes to CO_2 and to BIO + HUM is determined by the clay content of the soil. Each compartment decomposes by a first-order process with its own characteristic rate, which in turn is affected by the clay content of the soil, soil moisture, temperature, and soil cover. A more detailed description of the model and its processes can be found in Coleman and Jenkinson (1996), and Falloon and Smith (2009).

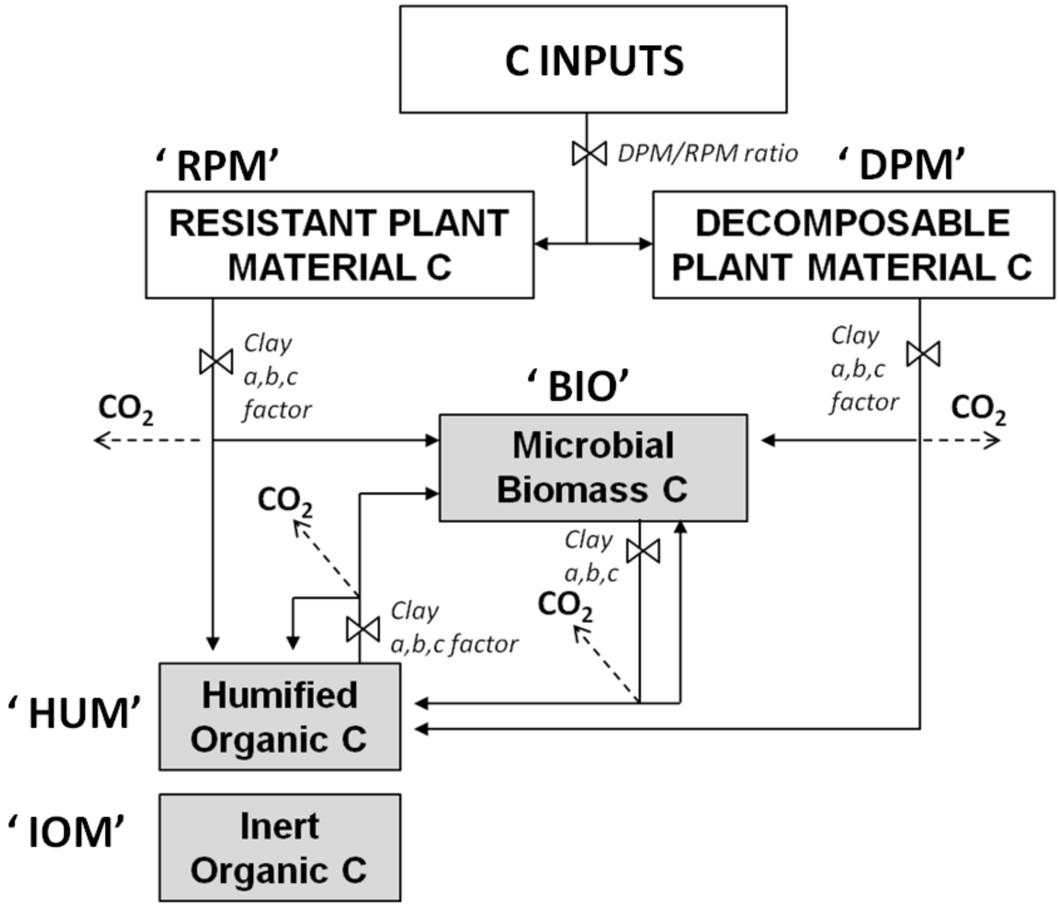

Figure 4 Structure, pools, and flows of carbon in the Roth-C model, including major factors controlling the fluxes (a = multiplier for effects of temperature, b = multiplier for effects of moisture, c = multiplier for effects of soil cover; DPM/RPM = Decomposable/resistant plant material ratio). *Source: redrawn from Coleman and Jenkinson (1996) and Falloon and Smith (2009).*

3.2 General procedures

Prior to the simulation of SOC stocks and sequestration under the different scenarios, model initialization is required to set the initial SOC condition (total SOC and partition of the different pools) at the start of the simulation period, and to adjust the C inputs estimates.

In a first initialization step, RothC shall be run iteratively to equilibrium to calculate the size of the SOC pools and the annual plant carbon inputs using constant environmental conditions (Phase 1, Figure 5), for each grid cell on the map. A first equilibrium run for a standard 10 000-year period should be performed, considering constant climatic conditions as the average of historic climate data from 1980 to 2000 (see section 3.3.1, Climate datasets), clay contents (see section 3.3.2.3, soil datasets), and land use as in year 2000 (see section 3.3.3.). The total annual plant C input can be initially assumed to be 1

$t\ C\ ha^{-1}\ yr^{-1}$ and the proportions of plant material added to the soil for each month are set to describe the typical input pattern for each land use class (Smith *et al.*, 2007; Mondini *et al.*, 2017).

After the first equilibrium run, the annual C input from plant residues needs to be optimized so that the results of the 'long spin-up' fit the estimates of total SOC stocks of 0–30 cm provided in the FAO-ITPS GSOC map. C equilibrium inputs can be adjusted using the following equation (Smith *et al.*, 2005):

$$C_{eq}=C_i\times[(SOC_{GSOCm}-IOM)/(SOC_{sim}-IOM)] \quad (3)$$

where C_{eq} is the estimated annual C input at equilibrium, C_i is the initial annual C addition (the sum of the proportions of the C input in the first equilibrium is 1), SOC_{GSOCm} is the estimated soil C given in FAO-ITPS GSOC map, SOC_{sim} is the simulated soil C after the first equilibrium run, and IOM is the C content of the inert organic matter fraction in the soil (all in $t\ C\ ha^{-1}$). The size of the IOM fraction ($t\ C\ ha^{-1}$) can be set according to the equation given by Falloon *et al.* (1998):

$$IOM=0.049\times(SOC_{GSOCm})\ \hat{}\ 1.139 \quad (4)$$

A second long term (minimum 1 000 years) equilibrium run shall be performed using the estimated C_{eq}, (under the same conditions as the first run), in order to obtain the size of the different SOC pools ($t\ C\ ha^{-1}$) at year 2000.

Since FAO-ITPS GSOC map SOC was generated from individual SOC measurements taken over different decades (i.e. 1960s to 2000s), a temporal harmonization of SOC stocks can be performed as a second initialization step to minimize differences in current SOC stocks at year 0 (i.e. initial SOC stocks at year 2020):

- SOC stocks from the GSOC map shall be considered to be the stocks twenty years prior to the simulation (t = -20 y; i.e. year 2000).
- A 20-year 'short spin-up' run can be performed to adjust for major deviations among different measurement periods on the GSOC map (figure 5, Phase 2), using year-to-year climatic conditions for the period 2001–2020 (section 3.3.1, Climate datasets), clay contents (section 3.3.2.3, soil datasets), the stocks in the different SOC pools from the results of the 'long spin-up' run, and land use as in year 2020 (land use representative of the period 2001–2020; or yearly land use data shall be used when available).
- Year-to-year C inputs over the period 2001–2020 should be adjusted considering year-to-year changes in estimated Net Primary Production (NPP), (details in section 3.3.5, monthly carbon inputs). SOC stocks can either increase or decrease during this 'short spin-up' stage.

This 'short spin-up' period is intended to: reduce the effects of different time measurements in the GSOC map (over- or underestimation of current initial SOC stocks); minimize initialization effects (e.g. deviations in the estimation of initial pool sizes); and account for the effects of sub-regional, regional and global climatic and land use changes over the period 2001–2020 and their effects on NPP. If recent (2015–2020) national SOC monitoring campaigns have been undertaken to generate the latest version of the FAO-IPS GSOC map, the SOC stocks from the GSOC map can be considered as the current stocks (t = 0 y; i.e. year 2020), and the 'short spin-up' phase is not required.

After the equilibrium and 'short spin-up' runs, SOC sequestration due to SSM practices can be estimated in a forward run (Figure 5, phase 3). SOC stocks can be simulated from 2020 (t=0) to 2040 (t = +20) for the BAU and the three SSM scenarios, using average mean monthly climate variables (2001–2020), and C inputs adjusted as described in section 3.3.5, and land use as in year 2020.

It should be noted that global climatic changes are to be expected over the next 20 years (climate change projections diverge significantly in the second half of the century, after year 2050; IPCC, 2014; 2018). As it is not yet certain which climate projections will be used for future scenarios and prior agreement between countries is needed, and as significant divergences in climatic variables are expected from 2050 onwards, the use of monthly average climatic variables from 2001–2020 for the period 2020–2040 is set as the standard for the forward run. However, the proposed methodology allows for the integration of climate change scenarios, especially for longer-term projections (i.e. + 2050) in future versions.

The attainable absolute SOC sequestration is to be estimated as the difference between the corresponding SOC stocks from the forward modeling at year +20 (2040) for the different scenarios and the estimated baseline SOC stocks for year 0 (year 2020; refer to equation 1). The attainable relative SOC sequestration is to be determined as the difference between the corresponding SOC stocks modeled forward at year +20 (2040) for the SSM scenarios and the simulated SOC stocks at year +20 (2020) for the BAU scenario (refer to equation 2).

The different modeling phases and their data requirements are summarized in Table 1.

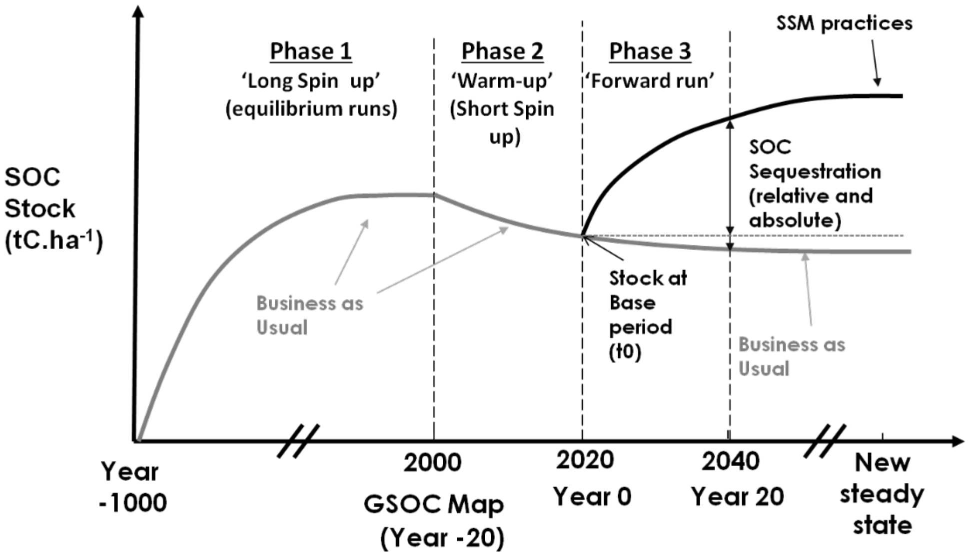

Figure 5. SOC stocks simulated in the different phases according to the proposed general modeling procedure.

Table 1. Summary of the different modeling phases and data requirements

	Phase 1 Long spin-up - Equilibrium	**Phase 2 Short spin-up**	**Phase 3. Forward modeling**
Time span	1 000 years	20 years	20 years
Climatic inputs	1980─2000 series monthly average: Rain, Temperature, Evaporation/ Evapotranspiration	2001─2020 year to year monthly data: Rain, Temperature, Evaporation/ Evapotranspiration	2001─2020 series monthly average: Rain, Temperature ,Evaporation/ Evapotranspiration
Soil inputs	Topsoil clay content	Topsoil clay content	Topsoil clay content
Initial SOC stocks and pools	Inert organic matter (IOM) as determined by equation 4 "= 0 " for all other fractions	Inert organic matter (IOM as determined by equation 4 Other fractions equal to the final SOC pools modeled in phase 1	Inert organic matter (IOM) as determined by equation 4 Other fractions equal to the final SOC pools modeled in phase 2
Carbon inputs	First run : 1tC.ha-1 Second run: Adjusted C inputs from equation 3	NPP year-to year adjusted C inputs, from equation 7	NPP year-to year adjusted C inputs for the BAU, from equation 7 Estimated from % increase vs. BAU for SSM scenarios
Vegetation cover	Monthly cover determined: by expert opinion, NDVI 2000─2020 or preferred spectral index (see section 3.3.4)	Monthly cover determined: by expert opinion, NDVI 2000─2020 or preferred spectral index (see section 3.3.4)	Monthly cover determined: by expert opinion, NDVI 2000─2020 or preferred spectral index (see section 3.3.4)
Modeled Scenarios	BAU	BAU	BAU, SSM Low, SSM Medium. SSM High
Expected Results	C inputs at equilibrium Total SOC and SOC pools at year t= -20 (2000)	Total SOC and SOC pools at year t=0 (2020)	Total SOC and SOC pools at year t=+20 (2040) for the BAU, and SSMs scenarios Absolute and relative Total Sequestration (3 SSMs) Absolute and relative Sequestration rates (3 SSMs)

3.3 Data requirements

The model requires climatic, soil and management data that are relatively easy to obtain or estimate. Each modeling unit (i.e. cell of a grid) requires the following minimum data (Table 2) at the different modeling phases:

Table 2. Roth-C model minimum data requirements

Climate data	Soil data	Land use- management data
1. Monthly rainfall(mm) 2. Average monthly mean air temperature (ºC) 3. Monthly open pan evaporation (mm)/evapotranspiration (mm)	1. Total Initial 0–30cm SOC stocks (t C ha^{-1}) 2. Initial C stocks of the different pools (t C ha^{-1}): DPM, RPM, BIO, HUM, IOM 3. Clay content (%) at simulation depth.	1. Monthly Soil cover (binary: bare vs. vegetated) 2. Irrigation (to be added to rainfall amounts) 3. Monthly Carbon inputs from plant residue (aboveground + roots + rhizodeposition), (t C ha^{-1}) 4. Monthly Carbon inputs from organic fertilizers and grazing animals' excretion (t C ha^{-1}) 5. DPM/RPM ratio, an estimate of the decomposability of the incoming plant material

Careful harmonization of datasets and input estimation methodologies is essential to obtain consistent results across regions and countries. Global sources are proposed (same resolution and quality) as standard datasets for soil and climate inputs for comparative purposes, although countries are encouraged to develop and deliver alternative SOCseq maps using national climatic and soil data. Land use and management activity data are expected to be country-specific.

3.3.1 Climate datasets

The gridded climate data shall be obtained from:

a) National Sources
b) Global datasets, when national agency gridded historical climate datasets are not available.

The dataset set provided by the Climate Research Unit, University of East Anglia, United Kingdom (developed following the methodology described in Harris *et al.*, 2014) at a resolution of 0.5° (~50x50 km) shall be used as the standard global dataset if national gridded data is not available, or if the available national data is at a coarser resolution. The CRU 2019 dataset (CRU TS v. 4.03) covers the period 1901–2018, including precipitation (pre), average/minimum and maximum air temperatures (tmp, tmn, tmx), Cloud percentage cover (cld), diurnal temperature range (dtr), vapor pressure (vap), number of rainy days (wet), frost days (frs), and potential evapotranspiration (pet); (See Table A1, Datasets and download sources).

The following variables and datasets are required to run the model (See section 3.2, General modeling procedures):

- Monthly average air temperature (°C),
- Monthly precipitation (mm),
- Monthly potential evapotranspiration (Penman–Monteith; mm)
- Datasets: 1981–1990; 1991–2000; 2011–2010; 2011–2018.

The same data sources must be used in all modeling phases.

3.3.2 Soil Datasets

3.3.2.1 Initial total SOC stocks

Initial total SOC stocks to 30cm depth (in t C ha^{-1}) are to be derived from the GSOCmap (30 arc seconds; ~ 1x1 km resolution grid), latest revised version (FAO-ITPS, 2019). Countries wishing to include an updated or improved estimate of current SOC stocks, compared to the latest version of the GSOCmap, are encouraged to submit their updated GSOCmap to the GSP Secretariat and use it for modeling.

Since the GSOC map was generated from national measurements taken between the 1960s and the 2000s, and no temporal corrections have been developed in many countries, GSOC map values will represent SOC stocks for the year 2000. A ‘short spin-up’ model run (20 years) with climate and management forcings for the period 2000–2020 shall be undertaken to reduce the effect of temporal deviations. Thus, the simulated SOC content at 2020 after the ‘short spin-up’ run will represent the initial SOC stocks prior to implementation of SSM practices (section 3.2, General modeling procedures). If recent national SOC monitoring campaigns (2015–2020) have been undertaken to generate the latest version of the FAO-IPS GSOC map, the SOC stocks from the GSOC map can be considered as the current stocks (t = 0 y; i.e. year 2020), and the ‘short spin-up’ phase is not required.

3.3.2.2 Initial C pools

The initial C stocks in the different pools (in t C ha^{-1}), (DPM, RPM, BIO, HUM and IOM, Fig. 4) shall be estimated following the ‘long spin-up’ and ‘short spin-up’ procedure described in section 3.2.

3.3.2.3 Soil texture: clay content

The average clay contents over 0–30 cm depth to be obtained from gridded data (raster format) from:

a) National Sources (1 km x 1 km resolution)
b) Global datasets, where national historic climatic datasets from national agencies are not available.

The topsoil clay content (0–30 cm, % mass fraction; 1 x 1 km resolution) from Harmonized World Soil Database – HWSD or SoilGrids ISRIC - International Soil Reference and Information Centre (see Table A1. Annex) shall be used as the standard global databases if national data is not available in the required format or resolution. Clay contents can be averaged at finer resolutions to obtain 1 x 1km grids.

Average clay contents over a 0–30 cm depth interval can be derived by taking a weighted average of the predictions over the depth interval using numerical integration (Hengl *et al.*, 2017).

$$\frac{1}{b-a}\int_a^b f(x)\,dx \approx \frac{1}{(b-a)}\frac{1}{2}\sum_{k=1}^{N-1}\left(x_{k+1}-x_k\right)\left(f(x_k)+f(x_{k+1})\right) \tag{5}$$

where N is the number of depths; b is 30 cm, a is 0 cm, x_k is the k-th depth and $f(x_k)$ is the value of the target variable (i.e., clay content) at depth x_k. For example, for the 0–30 cm depth interval, with soil clay values at the first four standard depths (0, 5, 15 and 30 cm) equal to 14.5, 25.0, 25.3 and 25.0, clay content 0–30 cm equals:

$$\{[(5-0)x(14.5+25.0)+(15-5)x(25.0+25.3)+(30-15)x(25.3+25.0)]/30\}x\ 0.5 = 24.25$$

3.3.3 Land cover datasets

The gridded land use data layers shall be obtained from:

a) National Sources
b) Global datasets, where national land use or land cover datasets are not available.

Since land cover may vary substantially between data sources and estimates of past and current land cover may have important deviations from real land cover and land use, users should estimate land use from the source that best reflects national and subnational conditions. Land cover datasets should cover the 2000–2020 (or approximate) period.

The ESA (European Space Agency) land cover Global dataset (Table A1, Annex), and its reclassification into FAO Global Land Cover - SHARE (GLC-SHARE; Table A1, Annex) classes will be provided by the GSP Secretariat, if no national land use dataset is available. However, users should estimate land use from the source that best reflects national and subnational conditions. Other global and regional datasets are provided in Table A1, Annex.

The land cover classes need to be re-classified into the three land use types that are implemented in the RothC: agricultural crops, grassland/shrubland/savannas and forestry. Examples of land cover reclassification into the RothC Land use categories are presented in Annex (Table A2). The spatialized R-version of RothC to be provided by the GSP Secretariat if necessary, runs considering the 11 classes defined in the FAO Global Land Cover - SHARE (GLC-SHARE).

As a minimum, land use for the year 2000 and land use for the year 2020 at 1x1 km resolution shall be defined. The predominant land use category in each cell of the 1x1 km grid shall be selected if finer resolutions are available.

3.3.4 Monthly vegetation cover

It is required to indicate the approximate annual distribution of monthly vegetation cover for the simulations in order to:

- adjust the topsoil moisture deficit estimations (and thus b coefficient = multiplier of the soil moisture effect, Fig. 4);
- take into account the effects of soil cover on SOC decomposition rates (c = multiplier of crop cover in Fig.4; bare c=1 and vegetated c=0.6)

The annual distribution of vegetation cover can be:

- derived from public statistics of national/administrative units considering the predominant agricultural systems in a temporal series (2000–2020). Plant cover is assumed to occur year-round in grasslands/shrublands and savannas and in specified months (e.g. 1–6) for croplands (e.g. Smith *et al.*, 2005; Smith *et al.*, 2007);
- derived from NDVI (normalized difference in vegetation index) values from historic satellite images (See datasets, Table A1):

  Considering a temporal series (2000–2020), the proportion of images with NDVI values greater than a specified threshold, indicating active vegetation growth, can be estimated (e.g. NDVI > 0.6). The monthly probability of being vegetated (P veg) can be estimated for each cell grid and each month of the year (1–12), as:

$$P\ veg = (\text{number images NDVI} > 0.6)/(\text{Total images}) \qquad (6)$$

NDVI is proposed as an alternative for estimating vegetation cover when no vegetation cover data or local knowledge is available. Global monthly vegetation cover datasets estimated by NDVI (2000–2020) will be provided by the GSP Secretariat. However, NDVI may be a biased indicator in areas with low vegetation cover (e.g. drylands, shrublands). In these cases, countries are encouraged to use other locally validated spectral indexes to accurately estimate monthly vegetation cover (e.g. Multi Sensor Vegetation Index; Moradizadeh and Saradjian, 2016).

3.3.5 Monthly carbon inputs:

3.3.5.1 C inputs under BAU practices:

Carbon inputs for the BAU scenarios shall be estimated using the approach proposed by Smith *et al.* (2005; 2006; 2007) and Gottschalk *et al.* (2012). Total plant C inputs to the soil, which include plant litter, root exudates and fine root turnover, are rarely known. To overcome this problem, the RothC shall be run in 'equilibrium mode' to calculate initial plant carbon inputs to the soil (or 'equilibrium Carbon inputs', Ceq), which led to specified initial SOC stocks (GSOC map), under historic forcing conditions. The Ceq thus represents the historical average annual carbon input of the BAU scenario up to year 2000. For further details on the equilibrium run and initialization to estimate Ceq, refer to section 3.2 (General modeling procedures).

Once these initial carbon inputs have been established, year-to-year changes (from year 2000 onwards) can be adjusted in accordance with changes in Net Primary Production (NPP), as changes in C inputs to the soil are assumed to be associated with changes in NPP (Smith *et al.*, 2005). Thus, annual C inputs for the BAU scenario can be adjusted as:

$$\text{BAU Ct} = \text{Ct-1} \times (\text{NPP t-1})^{-1} \times \text{NPPt} \qquad (7)$$

Where BAU Ct is the annual carbon input of a specific year t; Ct-1 is the annual carbon input of the previous year; NPP t is the net primary production of year t, and NPP-t is the NPP of the previous year (in tC ha^{-1}). Thus, the average NPP over the initialization period shall be associated with Ceq and the annual C inputs for the BAU scenario can be adjusted as:

$$\text{BAU Ct}_{2001} = \text{Ceq} \times (\text{NPP}_{1980\text{–}2000})^{-1} \times \text{NPP}_{2001} \qquad (8)$$

Where BAU Ct_{2001} is the annual carbon input for the first year of the 'short spin-up' phase; Ceq is the estimated annual C input at equilibrium derived through the 'long spin-up' process (eq. 3); $NPP_{1980\text{–}2000}$ is the estimated average net primary production over the initialization period (1980–2000); and NPP_{2001} is the estimated annual net primary production for the first year of the 'short spin-up' phase. The annual C inputs for the BAU scenario can be then adjusted following equation 7, according to changes in the NPP.

The estimation of NPP using the MIAMI model (Lieth, 1975) as the standard method is defined in this document. It requires little input and is easily applicable worldwide, can be used to estimate NPP under future climatic conditions, and can act as a baseline for different NPP datasets or projections (e.g. Gottschalk *et al.*, 2012). The equations of the MIAMI-model are given by:

$$\text{NPP}_{\text{MIAMI}} = \min(\text{NPPT}, \text{NPPP}) \qquad (9)$$

$$NPPT_{MIAMI} = 3000 /(1+\exp(1.315-0.119 \cdot T)) \quad (10)$$

$$NPPP_{MIAMI} = 3000 \cdot (1-\exp(-0.000664 P)) \quad (11)$$

where NPP is the climatic net primary production in dry matter (DM; g m^{-2} yr^{-1}), NPPT is the temperature dependency term of NPP, where T is the annual mean temperature (°C) and NPP P is the moisture dependency term of NPP, where P is the mean annual sum of precipitation (mm). NPP is limited by either temperature or precipitation. MIAMI model NPP can be expressed in t C ha^{-1} yr^{-1} as:

$$NPP_{MIAMI} (t\ C\ ha^{-1} \cdot yr^{-1}) = NPP_{MIAMI} (DM;\ g\ m^{-2}\ yr^{-1}) \times 0.01 \times 0.48 \quad (12)$$

Thus, the annual MIAMI NPP shall be estimated for each grid cell from the climatic datasets described in section 3.3.1 for the different simulation periods (1981–1990; 1991–2000; 2001–2010; 2011–2020; 2021–2040). The MIAMI NPP can thus be used to estimate BAU carbon inputs under current and projected climatic conditions.

The change in NPP is used as a surrogate for estimating the change in C-input and assumes that a similar proportion remains in the field (e.g. Smith *et al.*, 2005; Gottschalk *et al.*, 2012). In a first instance, countries should focus on C inputs in agricultural lands in 2020, the use of which has not changed since 2000. Changes in land use and management over the period 2000–2020 and associated changes in C inputs can nevertheless be taken into account, if trends in biomass removal are known, in order to adjust C-inputs (e.g. Schulze *et al.*, 2010; Plutzar *et al.*, 2016; Neumann and Smith, 2018). Thus, the annual changes in C inputs by equations 7 and 8 can be adjusted using annual land cover data. For example, by assuming and approving an NPP of 12, 28 and 47% for forests, grasslands and croplands (Schulze *et al.*, 2010), the annual NPP of a specific year (NPPt) can be adjusted using these coefficients, and the annual C inputs can then be estimated by equations 7 and 8:

$$NPPt_{forests} = NPP_{MIAMI} \times 0.88 \quad (13)$$

$$NPPt_{grasslands} = NPP_{MIAMI} \times 0.72 \quad (14)$$

$$NPPt_{croplands} = NPP_{MIAMI} \times 0.53 \quad (15)$$

3.3.5.2 C inputs under SSM practices:

SSM practices should be grouped into three scenarios as a standard method, based on their expected relative effects on C inputs compared to BAU: Low, Medium and High C inputs. The SSM practices considered in this approach are practices that affect C inputs to the soil, as changes in C inputs have been identified as one of the factors to which models are most sensitive when projecting changes in SOC stocks (FAO, 2019).

As with estimates of BAU C inputs, total plant C inputs to the soil, including plant litter, root exudates and fine root turnover, are rarely known. Thus, C inputs of SSM scenarios will represent a % increase from BAU C inputs:

$$\Delta\%C_{SSM\text{-}BAU} = (\text{C inputs SSM} - \text{C inputs BAU}) / (\text{C inputs BAU}) \qquad (16)$$

As a standard, the expected effects (% increase in C inputs) of 3 scenarios have been conservatively set at:

- Low: 5 % increase in C inputs
- Medium: 10% increase C inputs
- High: 20 % increase in C inputs

These percentages (based on Smith, 2004; Wiesmeier *et al.*, 2016) shall be used to produce the mandatory maps for the global product. An additional ‘High increase’ scenario, considering a 30% increase in C inputs, can be modeled, in order to compare results with recent ‘top-down’ modeling approaches (e.g. CIRCASA).

The use of default percentages in C input increase can be applied globally without complex configuration. However, countries should carefully check whether these scenarios are reasonable and under what type of management practices they are achievable. Countries are encouraged to produce and provide additional maps, taking into account their own estimates of the effects of different selected practices or land use changes, based on expert knowledge and local capacities. These effects can be determined on the basis of expert opinion and available information at the country level. A meta-analysis should be conducted on the basis of the latest available local and regional studies to estimate how agricultural practices affect average annual C inputs (and the % increase in C input compared to BAU practices). These practices may include, for example, the use of cover crops, rotation with high residue yielding crops or perennials, residue retention, grazing management, plant nutrition, species introduction, manure or organic amendment application, among others. If no data is directly provided in the compiled studies, carbon inputs and % increase in C inputs relative to BAU practices shall be estimated taking into account the framework proposed by Bolinder *et al.* (2007). A template for data compilation is also presented in Annex A3.

The annual C inputs required to model the effects of SSM practices under 3 scenarios (Low, Medium, High) for each modeling unit (i.e. grid cells) shall be estimated from the annual BAU C inputs:

$$\text{SSM Ct (t C ha}^{-1}\text{ yr}^{-1}) = \text{BAU Ct} + \%\ \Delta C_{SSMi\text{-}BAU}\ .\ \text{BAU Ct} \qquad (17)$$

where SSM Ct represents the estimated annual C inputs for a specific scenario (i =Low, Medium, High) for year t; BAU C t represents the estimated annual C inputs for the BAU scenario for year t (determined from C inputs at equilibrium, as explained at the beginning of this section and in section 3.2), and $\Delta\%C_{SSMi\text{-}BAU}$ is the representative % increase in C inputs for a specific scenario (i=Low, Medium, High).

3.3.6 Residue decomposability: decomposable to resistant plant material ratio (DPM/RPM)

Default values for the DPM/RPM ratio (decomposability of incoming plant material) can be used (1.44 for crops and improved grasslands; 0.67 for unimproved grasslands and shrublands, and 0.25 for forests, woodlands and tree crops; Falloon and Smith, 2009), but can be modified according to region-specific data.

4. Product specifications

4.1 Mandatory products

- **SOC sequestration maps:** Includes country-level predicted topsoil (0–30 cm) SOC stocks and mean annual sequestration rates after the implementation of SSM practices, over a 20-year period, estimated with the spatialized version of the RothC carbon model. Each pixel shall contain:
    - Absolute average (vs. t0) sequestration rates for 20 years (t C ha^{-1} yr^{-1}), for BAU, SSM1, SSM2 and SSM3 scenarios
    - Mean relative (vs. BAU) sequestration rates for 20 years (t C ha^{-1} yr^{-1}), for SSM1, SSM2 and SSM3 scenarios
    - Initial SOC stocks at t0 (t C ha-1)
    - SOC sequestration uncertainty maps (absolute and relative sequestration rates) for 3 SSM Scenarios (in %, see section 5 Uncertainties)
- **Country report** (electronic document) according to the submission form provided by GSP-FAO.

4.2 Optional datasets

Country members are encouraged to deliver the following products and supplementary data:

- Final SOC stocks at 2040 (t C ha^{-1}), for BAU, SSM1, SSM2 and SSM3 scenarios;
- SOC sequestration maps using alternative modeling procedures: Includes country-level topsoil (0–30 cm) predicted SOC stocks and mean annual sequestration rates after implementation of

SSM practices, for a 20-year period (2020–2040), estimated using: alternative SSM scenarios (e.g. alternative C % increase based on local data analysis); alternative local preferred, process-oriented and peer-reviewed models (e.g. CENTURY/DAYCENT, DNDC, YASSO, ICBM, or their derived models). As in the previous case, each pixel shall contain:

  - Absolute mean (vs. t0) sequestration rates 2000–2020 (t C ha^{-1} yr^{-1}), for BAU, SSM1–SSM3 scenarios.
  - Mean relative (vs. BAU) sequestration rates 2000–2020 (t C ha^{-1} yr^{-1}), for SSM1–SSM3 scenarios.

- Meta-analysis on the local impact of SSM management practices on SOC sequestration (See section 2.2, A3)
- Validation dataset (results from predicted vs. observed SOC stocks/SOC sequestration rates from meta-analysis and RMSE; validation dataset in table format; shapefile/points if georeferenced data is available; See section 5 uncertainty and validation; and Annex A3 for template)

4.3 Spatial entity

4.3.1 Horizontal and vertical resolution

The first product of the GSOCseq will be given in one depth (0–30 cm). Although SOC at deeper soil layers is responsive to land management changes (e.g. Follett *et al.*, 2013; Poeplau and Don, 2013; Schmer *et al.*, 2014), the 0–30 cm is selected because: it is most responsive to land management changes; allows the use of GSOCmap as a baseline for SOC stocks; allows for better harmonization with national greenhouse gas inventories, and allows validation of selected models with available ground data (mostly generated at 0–30cm depth).

The map shall be produced at regular fixed horizontal dimensions of 30 by 30 arc-seconds grid (approximately only 1x1km) at the equator.

4.3.2 Spatial reference

World Geodetic System 1984 (WGS84) geographic (latitude/longitude) projection will be preferred for all submitted maps. The final GSOCseq map will also be delivered at this coordinate reference system.

4.3.3 Extent

A generic, empty, global 30 arc-second grid will be prepared and shared with all participating countries. Countries will be expected to deliver their datasets using these standard grids.

4.3.4 Excluded areas

Data providers are expected to deliver a continuous surface for their predictions, for both croplands and grazing lands. Data providers should not attempt to mask out the excluded areas from the grid (e.g.

saline soils, organic soils, wetlands). The GSP Secretariat will mask excluded areas using standard spatialized layers. Values in the excluded grid cells will be identified as no data (NA) in the final global product.

5. Uncertainties and validation

Ideally, the model prediction uncertainty provided in the GSOCseq map should include all sources of uncertainty affecting the predictions, including model structural uncertainty, model parameter and input data uncertainties. As a minimum, uncertainty should include input data uncertainties (e.g. Morais *et al.*, 2019). Approaches for uncertainty quantification and validation will be elaborated in the GSOCseq Technical Manual.

6. Data submission

6.1 File naming conventions and directory structure

The GSP Secretariat will provide an online data submission facility. Deliverables can be uploaded as individual files or as compressed archives of files (.zip, .rar, 7z).

Structure is as follows:

|_ Maps

- **|_ National Absolute SOC Sequestration rate Map for the BAU scenario** *(ISO3CountryCode_* **GSOCseq_ASR_BAU_***Map030.tiff)*
- **|_ National Absolute SOC Sequestration rate Map for the SSM1 scenario (Low)** *(ISO3CountryCode_* **GSOCseq_ASR_SSM1_***Map030.tiff)*
- **|_ National Absolute SOC Sequestration rate Map for the SSM2 scenario (Medium)***(ISO3CountryCode_* **GSOCseq_ASR_SSM2_***Map030.tiff)*
- **|_ National Absolute SOC Sequestration rate Map for the SSM3 scenario (High)***(ISO3CountryCode_* **GSOCseq_ASR_SSM3_***Map030.tiff)*
- **|_ National Relative SOC Sequestration rate Map for the SSM1 scenario (Low)** *(ISO3CountryCode_* **GSOCseq_RSR_SSM1_***Map030.tiff)*
- **|_ National Relative SOC Sequestration rate Map for the SSM2 scenario (Medium)***(ISO3CountryCode_* **GSOCseq_RSR_SSM2_***Map030.tiff)*
- **|_ National Relative SOC Sequestration rate Map for the SSM3 scenario (High)***(ISO3CountryCode_* **GSOCseq_RSR_SSM3_***Map030.tiff)*
- **|_ Initial SOC Stocks at T0** *(ISO3CountryCode_* **GSOCseq_T0_***Map030.tiff)*

|_ Uncertainty Maps

- **|_ Uncertainties: National Absolute SOC Sequestration rates for the BAU scenario** *(ISO3CountryCode_* **GSOCseq_ASR_BAU_***UncertaintyMap030.tiff)*
- **|_ Uncertainties: National Absolute SOC Sequestration rates for the SSM1 scenario (Low)** *(ISO3CountryCode_* **GSOCseq_ASR_SSM1_** *UncertaintyMap030.tiff)*
- **|_ Uncertainties: National Absolute SOC Sequestration rates for the SSM2 scenario (Medium)***(ISO3CountryCode_* **GSOCseq_ASR_SSM2_** *UncertaintyMap030.tiff)*
- **|_ Uncertainties: National Absolute SOC Sequestration rates for the SSM3 scenario (High)***(ISO3CountryCode_* **GSOCseq_ASR_SSM3_** *UncertaintyMap030.tiff)*
- **|_ Uncertainties: National Relative SOC Sequestration rates for the SSM1 scenario (Low)** *(ISO3CountryCode_* **GSOCseq_RSR_SSM1_** *UncertaintyMap030.tiff)*
- **|_ Uncertainties: National Relative SOC Sequestration rates for the SSM2 scenario (Medium)***(ISO3CountryCode_* **GSOCseq_RSR_SSM2_** *UncertaintyMap030.tiff)*
- **|_ Uncertainties: National Relative SOC Sequestration rates for the SSM3 scenario (High)***(ISO3CountryCode_* **GSOCseq_RSR_SSM3_** *UncertaintyMap030.tiff)*

|_ Documents

- **|_ Report** (ISO3CountryCode_Report.doc, docx)

6.2 File formats

GIS files shall be delivered in GeoTIFF format. GeoTIFF is a standard .tif or image file format that includes additional spatial (georeferencing) information embedded in the .tif file as tags. These are called embedded tags, tif tags. These tags include raster metadata such as spatial extent, coordinate reference system, resolution, no data values.

7. Quality assurance/quality check

Each country will be responsible for carrying out basic Quality Assurance/Quality Control (QA/QC) of all data before providing it to the GSP Secretariat. Quality Assurance can be described as the process of preventing errors from entering the datasets; while Quality Control can be described as the process of identifying and correcting existing errors in the datasets.

All datasets should be checked for:

- Spatial errors (extent, projection)
- Units (tC $ha^{-1}yr^{-1}$)
- Completeness of data
- Consistency with data shown in any accompanying documents (such as reports or drawings)

- Compliance with the Data Standards described in this document.
- Consistency of reported validation results with the provided data.

Final QA/QC for the global datasets will be facilitated by the GSP Secretariat through its technical networks (INSII, P4WG, and Intergovernmental Technical Panel on Soils (ITPS) will give final clearance to the global dataset prior to public release).

8. Data policy

The final global dataset will be distributed under the endorsed GSP Data Policy (http://www.fao.org/3/a-bs975e.pdf). As suggested in the GSP Data Policy, a Creative Commons license will be assigned to the global dataset. Data providers will retain the ownership of national datasets. Detailed recommendations on product licensing will be provided by the Pillar 4 Working Group.

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ANNEX

A1. Global and regional data sources

Type	Source	Address	Resolution
Climatic monthly data	CRU – Climate Research Unit , University of East Anglia	https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.03/cruts.1905011326.v4.03/	50 km x 50 km
SOC stocks 0–30 cm	GSOCmap - FAO-ITPS	http://54.229.242.119/GSOCmap/	1 x 1 km
Soil Texture	Harmonized World Soil Database v1.2	http://www.fao.org/soils-portal/	1 km (30 arc seconds by 30 arc seconds)
Soil Texture	OpenGeoHub Foundation - OpenLandMap	https://doi.org/10.5281/zenodo.1476854	250m
Soil texture, including uncertainties	Soil Grids -ISRIC	http://soilgrids.isric.org	250 m
NDVI- Historic images (2001-2020) every 16 days	MODIS - MOD13A2 datasets	https://lpdaac.usgs.gov/products/mod13a2v006/	1 x 1km

Land Cover	MODIS Land Cover Dynamics MCD12Q2	https://modis.gsfc.nasa.gov/data/dataprod/mod12.php	500 x 500m 1 x 1 km
Land Cover	European Space Agency (ESA) Climate Change Initiative (CCI)-Copernicus Climate Change Service (C3S)	https://www.esa-landcover-cci.org/	300 x 300m
Land Cover – Land Use	FAO. Global Land Cover SHARE	http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036355/	~1 x 1km
Land Cover	USGS Global Land Survey	https://lta.cr.usgs.gov/GLS	30 x 30m
Land Cover	CORINE land cover (Europe only)	https://land.copernicus.eu/pan-european/corine-land-cover	100 x 100 m

A2. Land cover aggregation schemes. Example from ESA land cover classes.

ESA Land Cover Class	ESA class Number	IPCC Land Use Type	RothC Land Use type (DPM/RPM parameter)
Cropland Rainfed	10	Croplands. Annual crops	Agricultural crops/improved grassland
Cropland rainfed herbaceous cover	11		Agricultural crops/improved grassland
Mosaic Cropland > 50%	30		Agricultural crops/improved grassland
Cropland - Tree/shrub cover	12	Croplands. Perennial/Tree crops	Forest/Deciduous/tropical woodland
Cropland irrigated flooding	20	Croplands. Paddy-rice/regularly Flooded	Waterlogged soils -9999
Grasslands	130	Grasslands	Unimproved grassland and scrub (including Savanna)
Mosaic Natural vegetation herbaceous > 50% /cropland	40		Agricultural crops/improved grassland
Mosaic herbaceous cover >50%/trees-shrubs	110		Unimproved grassland and scrub/ Savanna
Shrubland	120	Shrublands	Unimproved grassland and scrub/ Savanna
Shrubland evergreen	121		
Shrubland deciduous	122		
Tree cover broadleaved deciduous open 15–40%	62	Savannas/woodlands	
Tree cover needleleaved deciduous open 15–40%	82		
Tree cover broadleaved evergreen closed to open >15%	50	Forestlands	Forest/Deciduous/tropical woodland
Tree cover broadleaved deciduous closed to open >15%	60		
Tree cover broadleaved deciduous closed >40%	61		

Tree cover needleleaved evergreen closed to open >15%	70		
Tree cover needleleaved evergreen closed >40%	71		
Tree cover needleleaved evergreen open >40%	72		
Tree cover needleleaved deciduous closed to open >15%	80		
Tree cover needleleaved deciduous closed >40%	81		
Tree cover mixed leave type	90		
Mosaic tree-shrub >50%/herbaceous cover	100		Forest/Deciduous/tropical woodland
Shrub or herbaceous flooded fresh/saline/brackish water	180	Wetlands	Waterlogged -9999
Tree cover flooded fresh or brakish water	160		
Tree cover flooded saline water	170		
Urban areas	190	Settlements	-9999
Lichens and mosses	140	Others	Others - No data-9999
Bare areas	200		
Sparse vegetation tree-shrub-herbaceous (<15%)	150		
Sparse tree (<15%)	151		
Sparse Shrub (<15%)	152		
Sparse herbaceous (<15%)	153		
Consolidated bare areas	201		
Unconsolidated bare areas	202		
Permanent snow/ice	220		
Water bodies	210	Water	
No data	0	No Data	

cover classes= “−9999” denotes areas to be excluded without adaptations in the RothC model.

A3. Template to compile data to estimate SSM C inputs and SOC sequestration rates

Source	Study Reference/Source
Location	Nearest location (coordinates if available)
Climate type	IPCC 2019 Climate type
Soil type	IPCC 2019 Soil type
Clay content	If available, (%) 0–30 cm depth
Sand content	If available, (%) 0–30 cm depth
SSM Practice/s	Description. E.g. cover crop; cover crop + P fertilizer
BAU Practice/s	Description. E.g. Maize- Soybean –wheat/Soybean; no cover crops
Duration	years
BAU C inputs	Provided by the source or estimated from yields (tC.ha-1.yr-1)
SSM C inputs	Provided by the source or estimated from yields (tC.ha-1.yr-1)
ΔCSSM-BAU	C input increase from BAU (tC.ha-1.yr-1)
Δ%CSSM-BAU	C input increase from BAU (%)
Baseline C stock	SOC stocks at the beginning of the experiment/trial , if available (tC.ha-1)
Final C stock BAU	SOC stocks at the end of the experiment/trial under BAU management, if available;(tC.ha-1)
Final C stock SSM	SOC stocks at the end of the experiment/trial under SSM management, if available;(tC.ha-1)
Absolute Seq rate	equation 1; (tC.ha-1.yr-1)
Relative Seq rate	equation 2; (tC.ha-1.yr-1)

GLOBAL SOIL PARTNERSHIP

The Global Soil Partnership (GSP) is a globally recognized mechanism established in 2012. Our mission is to position soils in the Global Agenda through collective action. Our key objectives are to promote Sustainable Soil Management (SSM) and improve soil governance to guarantee healthy and productive soils, and support the provision of essential ecosystem services towards food security and improved nutrition, climate change adaptation and mitigation, and sustainable development.

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