Many thanks for your attention

Global Soil Organic Carbon Sequestration Potential Map

GSOCseq

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Technical Workshops. 2022
Soil Organic Carbon is the largest terrestrial carbon pool

Global Stock
~680 Gt (0-30 cm)

(1 Pg = 1 Gt = 1000 million tons)

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Due to the magnitude of SOC pool, small increases in SOC stocks can transform soils into potential carbon sinks (Paustian et al., 2016).

CO₂ sequestration as SOC through sustainable management practices has been outlined as one of the most cost-effective practices to mitigate GHG emissions (Smith et al., 2008; Lal et al., 2018; IPCC, 2019; Smith et al., 2020).

Besides other benefits linked to SOC increase: soil structure, water infiltration and retention, nutrient cycling, etc
SOC sequestration

C inputs
- Crop residues
- Root biomass
- Rhizodepositions
- Manure

C losses
- Residue Removal
- Decomposition/Mineralization
- Erosion
- Leaching (DOC)

Adapted from Lal, 2020
<0.1 to 2.2 t C ha\(^{-1}\) year\(^{-1}\) (Poepleau and Don, 2015; Kampf et al., 2016; Minasny et al., 2017; Conant et al., 2017; Paustian et al., 2016; Paustian et al., 2019).

75 studies

SOC sequestration rate (kg C. ha\(^{-1}\) . yr\(^{-1}\))
We have a better understanding of current SOC stocks...

SOC sequestration/mitigation potential?
Soil types? Climates? Regions?
Productive systems?
Why GSOC$_{seq}$ map?

Objective

- Identify which regions and productive systems show higher potential to increase SOC stocks, following harmonized and standardized procedures among countries

establish priorities for research and public and private policies

Support countries to develop Climate change adaptation and mitigation strategies, and sustainable development

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¿Why GSOC\textsubscript{seq} map?

Country-Driven GSOC\textsubscript{seq} product. Strengths:

- Local expertise, based on best available local data ("bottom-up")
- Inclusive process, involving specialists from different fields and institutions
- Continuous improvement process; "living product"
How is the GSOCseq Country-driven process?

1. FAO Members/GSP partners request
2. Collection of feedback
3. Action on the ground
   - Monitoring sites to validate results
   - Implementation SSM practices
4. Country-driven GSOCseq

Methodology
Through the support of the GSP’s technical networks
Taking into considerations potential data and computational limitations

Technical specifications and country guidelines
Reviewed INSII, ITPS, CIRCASA, 4p1000, UNCCD

Capacity Building Program
Online Technical Manual
Online regional trainings

National Maps and Submissions

Permanently updated Submissions

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Country Driven GSOCseq. Workshops

- Trainings/exchange workshops
- Harmonization of procedures and methodologies among countries
- Integration of experts among countries and within each country
DAY 1 (3h) - Opening and Introduction
1. High-Level opening (Dr. Park Joungyoon, AFACI Senior Deputy Secretary General, AFACI Secretariat): 10’
2. Introduction: The GSOCseq Initiative (importance, the process, benefits, timeline), General framework (BAU, SSM1-SSM2-SSM3, Meta-Analysis), Product specifications, discussion and feedback on national capacities

DAY 2 (3h) - Introduction to sequestration modelling
1. Introduction to sequestration modelling (RothC Basics), Input data requirements; uncertainties, software and tools (R, QGIS and Google Earth Engine to be used during the training)
2. Introduction to the R language and RStudio
3. Input data preparation: running Scripts 0 to 9

DAY 3 (3h) – Input data preparation
1. Input data preparation (continuation of Day 2): running Scripts 0 to 9
2. Harmonization of spatial layers

DAY 4 (3h) – Modeling and Mapping SOC sequestration Potential
1. Modeling and Mapping stage: running Scripts 9-16
2. Hands-on break out room session: applying the methodology to national data

DAY 5 (3h) - Review and Implementation
1. Review and interpretation of the results and QA
2. Hands-on break out room session
How?
Framework

1. Technical Specifications

2. Technical Manual
   https://fao-gsp.github.io/GSOCseq/

Contributors and reviewers

- P4WG - Pillar 4 Working Group
- 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
**Scope:** Agricultural lands ("Croplands, grasslands" IPCC)

**How? Framework**

...In a first stage...

- Annual crops
- Perennial Crops
- Integrated crop livestock systems
- Perennial sown pastures

- Grasslands, shrublands and savannas (grazing lands) Agro forestry; silvo pastoriil

Magnitude of global agricultural area,
Annual management; Higher probability to implement SSM practices
Linked to programmes like RECSOIL (encourage SSM by farmers)
How?
Framework - SOC sequestration

[Diagram showing SOC stock over time with SSM practices and differences compared to Business as Usual]
How?
Framework

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How?
Framework

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How?
Framework

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Annual Sequestration rate = $\Delta$ SOC / 20 years

Absolute sequestration rate = (Final SOC SSM 2040– Initial SOC 2020)/ 20 years

Relative Sequestration rate= (Final SOC SSM 2040– Final SOC BAU 2040)/ 20 years
How?
Framework -Summary

• 20-year projection
• After the adoption of SSM that increase C inputs
• 0-30 cm Depth (GSOC, IPCC, Activity data to validate the model)
• Absolute and relative SOC sequestration rates, average 20 years
• In current agricultural lands (Each country can model preferred land uses, restoration, etc.)

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Vegetation cover

NDVI-/ expert opinion

RothC spatial Platform

(1km x 1km)

Monthly
Monthly Rain
Monthly - Evapotranspiration

Clay 0-30

Current Stocks 0-30 cm

NPP MIAMI model (from Temp and PP)

Land use

Vegetation cover NDVI-/ expert opinion

Monthly Temp Monthly Rain - Monthly

Evapotranspiration

Clay 0-30

Current Stocks 0-30 cm

Low Scenario: +5%

Medium Scenario: +10%

High Scenario: +20%

Management Layers

Climate layers

Soil Layers

GSOC

Harmonization

Stack

RothC spatial Platform

(R)

Phases

Phase 1 (Spin Up)

Phase 2 (Warm Up)

Phase 3 (Forward Modeling)

SOC 20 years BAU

SOC 20 years Low Scenario

SOC 20 years Medium Scenario

SOC 20 years High Scenario

Absolute and relative Sequestration rates

7 products

(29 intermediate products)
Why RothC as standard model?

- **Standard method** among countries (DayCent, Century, ICBM, YASSO, DAISY, AMG, CLM5, etc)
- Fewer **data requirements**; data relative simple to obtain;
- It has been applied across several ecosystems, climate conditions, soils and land use classes;
- 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. (2014), 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**; Smith et al. (2020): Australia (as part of the FullCam model), Japan (modified RothC), Switzerland, and UK (CARBINE, RothC).
# RothC Data requirements

## Climate

1. Monthly rainfall (mm)
2. Average monthly mean air temperature (°C)
3. Monthly open pan evaporation (mm)/evapotranspiration (mm)

## Soil

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.

## Management

1. Monthly Soil cover (binary: bare vs. vegetated)
2. Irrigation (to be added to rainfall amounts)
3. Monthly Carbon inputs from plant residues (aboveground + belowground), (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
2. Country driven Approach
RothC

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SOC dynamics in RothC

The amount of SOC of each pool ($Y$) decomposes following an **exponential decay function:**

$$Y \cdot e^{-kt}$$

- $k =$ annual decomposition constant
- $t =$ time, months $1/12$ (0.083)

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Decomposition rates

Constants \((k)\), in years\(^{-1}\), different for each pool:

- DPM (decomposable plant mat): \(10.0\) .... 0.1 years (turnover time)
- RPM (resistant plant material): \(0.3\) ......3.3 years
- BIO (microbial biomass): \(0.66\) ............ 1.5 years
- HUM (Humified organic C): \(0.02\) ............... 50 years
- IOM (Inert) .....0.000000 ................. \(\alpha\)
SOC dynamics in RothC

... These $k$ are affected by different factors:

$$Y_e^{-kt} \rightarrow Y_e^{-k \cdot a \cdot b \cdot c \cdot t}$$

$a = \text{temperature factor}$

$b = \text{soil moisture factor}$

$c = \text{soil cover factor}$

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Temperature factor (a)

> Temperature,
> decomposition rate

From: CSIRO: 2008
Soil moisture factor (b)

Dryer conditions (> deficit)... Lower b, Lower decomposition rate

rate modifying factor

water holding capacity (mm) / TSMD

(Total Soil moisture deficit)
From Clay %

Monthly balance ET-PP

if Et – PP exceeds 0.44 of TMSD, b decreases 0.2

0.44 Max TMSD

Max TMSD e.g. 44
Soil/vegetation cover factor (c)

If soil is vegetated $c=0.6$
If soil is bare $c=1.0$

If Vegetated, Lower “c” Lower decomposition rate

July
No crops Bare; $c=1.0$

January
Growing crops veg.; $c=0.6$

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Example RothC Japan – Paddy Rice - watterlogged soils

The model underestimated SOC, as expected (slower decomposition because of anaerobic condition)

From: Yirato y Yagasaki. NIAES

(Shirato & Yokozawa, 2005)

Modifying factor for paddy rice

0.6 x k months no flooded rice
0.2 x k with flooded Rice

Paddy rice modifying factor
GSOCseq= 0.4 x k
Clay% affects the proportion of C from each pool that is released as CO$_2$ or to Soil organic carbon pools:

- From that... 46% goes to BIO; 54% goes to HUM

> Clay % > % to BIO+HUM, less as CO$_2$
DPM/RPM... “Decomposability of C inputs”
C inputs split between DPM and RPM

Default values...

- Crops and improved pastures...
  \[ \text{DPM/RPM} = 1.44 \]  (59% is DPM, 41% is RPM)

- Grasslands, shrublands/savannas
  \[ \text{DPM/RPM} = 0.67 \]  (41% is DPM; 59% is RPM)

Tree crops
variable...\[ \text{DPM/RPM} = 1.44; 0.67; 0.35 \]
(Morais et al 2019; Farina et al 2017)

- Forests (deciduous, tropical)...
  \[ \text{DPM/RPM} = 0.25 \]  (20% is DPM y 80% is RPM)

- Manure...
  \[ \text{DPM/RPM} = 1 \]  (49% is DPM; 49% is RPM; 2%HUM)

Depends on Land Use
Can be modified
RothC – Soil R

Sierra et al., 2012; 2014

SoilR - simplified version of RothC – Higher speed, adapted to simulate multiple objects (e.g. 1 km x 1 km)

• Transparent, R language, can be modified

• Open Software (R)

• SoilR, already integrates other SOC models (e.g. ICBM, Century)...to perform model ensemble approach


Soil R site:

https://www.bgc-jena.mpg.de/TEE/software/soilr/

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Spatial Version RothC Soil-R

- GSP: We provide a tool based in R language using Soil R – RothC functions

- Each country can improve and modify the tool, develop their own tool (using Roth C to generate the standard products in a first stage)

- Countries are encouraged to provide additional (‘non-standard’) sequestration maps, using modifications/adaptations, alternative approaches, other models
Conservative ranges...may be high for other systems

Practices that increase C inputs

3 scenarios:
• +5% increase Ci
• +10% increase Ci
• +20% increase Ci

based on Smith, 2004; Wiesmeier et al., 2016
SSM practices

“Technical manual of recommended management practices for SOC maintenance and Sequestration”

...and many other practices around the world...
Local adjustment of scenarios and % increase in C inputs

E.g.

Ad hoc Meta-analysis from local studies

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Local adjustment of scenarios and % increase in C inputs

E.g. Ad hoc Meta-analysis from local studies

**Croplands**

![Box plots for C input increase in croplands](image)

**Grazing lands**

![Box plots for C input increase in grazing lands](image)
Local adjustment of scenarios and % increase in C inputs

E.g.

- Croplands:
  - SSM1 - Low: +10%
  - SSM2 - Medium: +25%
  - SSM3 - High: +50%

- Grazing lands:
  - SSM1 - Low: +5%
  - SSM2 - Medium: +30%
  - SSM3 - High: +70%

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Standard Products

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Non-Standard Products
Using modified coefficients

Low
(+10% crop ; +5% grass)

Medium
(+25% crop ; +30% grass)

High
(+50% crop ; +70% grass)

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To simulate SOC changes for each 1km x 1km pixel:

Based on Smith et al 2006; 2008; Gottschalk et al 2012

Fig. 7. Average trend in SOC concentration of all 10 scenarios from 1971 to 2100.

Gottschalk et al 2012

Smith et al 2006

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For each 1km x 1km pixel:

- **Phase 1**: Long ‘Spin up’; initialization (equilibrium or analytical approach)
- **Phase 2**: ‘Warm-up’ (short spin up)
- **Phase 3**: ‘Forward’

Approach based on Smith et al. 2006; 2008; Gottschalk et al. 2012
Phase 1. Spin up

- Initialization phase

Required to:
- obtain C stocks of different pools (BIO, HUM, DPM, RPM, etc)
- Estimate baseline C-inputs (C inputs required to reach GSOC stocks) (referred as C_eq)
  
  \[
  C_{eq} = C_{i} \times \left[ \frac{(C_{meas} - IOM)}{(C_{sim} - IOM)} \right]
  \]

Procedure:
Model is run for a long time span (e.g. 500 years) using historic climate (1980-2000)... first using a fixed C input (1 t)... C inputs are adjusted until SOC stock = GSOC map:
Phase 2. Warm up – Short Spin up (18-20 years)

**Required to:**
- Adjust climate variation between 2000-2020
- Harmonize major time differences in GSOC map FAO (generated soil profiles 1960-2000s)... current
- Adjust Land use changes 2000-2020
- Adjust over or under estimation in C stocks of a specific pool (E.g. High DPM)
- Not necessary if current SOC stocks = GSOC

**Procedure**
- The model is run for 18-20 years using monthly climate data, year to year (2001-2020)
- Annual C inputs are corrected according to annual changes in NPP

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• Annual NPP to adjust year to year C inputs
• NPP by MIAMI Model (Lieth, 1972; Gottschalk et al., 2012)
• Other preferred NPP sources/models can be used

NPP can be adjusted for Land Use changes (Schulze et al. 2010)

NPP_{t_{forest}} = NPP_{MIAMI} \times 0.88

NPP_{t_{grasslands}} = NPP_{MIAMI} \times 0.72

NPP_{t_{croplands}} = NPP_{MIAMI} \times 0.53
Phase 3. Forward run (2020 – 2040)

- Required to:
  - Obtain SOC stocks in different SSM scenarios after 20 years
  - Estimate SOC sequestration rates

Procedure:
- Model is run for 20 years using average climate 2000-2020
- (Future versions include climate change... decide scenarios)

- The 4 scenarios are run:
  - BAU
  - SSM1 ('Low increase') (+5% in C)
  - SSM 2 ('Medium increase') (+10%)
  - SSM 3 ('High increase'): (+20%)
Validation and uncertainties

Difficulties

• Validate changes that did not happen yet?
• Complex methods (e.g. Montecarlo) require multiple simulations (computational time)
• Data availability, uncertainty in input layers

• We require to estimate uncertainties with limited computational and data resources
1st Step

Model evaluation with pre-existent data

Meta-analysis local studies

RMSE average = 4.92%

\[ y = 0.8245x + 13.932 \]

\[ R^2 = 0.8633 \]

Fuente: Studdert et al., 2011

Fuente: Montiel et al., 2018

Fuente: AAPRESID 2020

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2nd Step

General Uncertainties

\[ U(\%) = 100 \times \frac{(UL\ CI - LL\ CI)}{2 \times SOCav} \]

- UL = upper limit of the 95% confidence interval of the estimated SOC at the end of the simulation (in t C.ha\(^{-1}\)),
- LL = lower limit of the 95% confidence interval of the estimated SOC at the end of the simulation (in t C.ha\(^{-1}\)); a
- SOCav = the average of the estimated SOC at the end of the simulation (t C.ha\(^{-1}\))

\[ SOC\ max/UL = Model\ (SOC\ FAO\ max, Ci\ max, Temp\ min, Pp\ max, Clay\ max) \]

\[ SOC\ min/LL = Model\ (SOC\ FAO\ min, Ci\ min, Temp\ max, Pp\ min, Clay\ min) \]

VCS 2012

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General Uncertainties

SOC Stock (tC.ha⁻¹)

Phase 1
'Spin up'

Phase 2
'Warm-up'

Phase 3
'Forward'

For Scenarios
Max
Med
Min

Year -10,000 a -500

GSOCS Map (Year -20)

Year 0

Year 20

2000

2020

2040

New equilibrium

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If information on uncertainty of layer for each pixel 1 km x 1 km (SOC FAO, PP, Clay, Temp, etc):

\[ P_{\text{min}} = X_p - 1.96 \times SE_p \]
\[ P_{\text{max}} = X_p + 1.96 \times SE_p \]

And run model changing Input Layers (using Pmin, Pmax).

If NO information on the uncertainties of each layer, use general variation (> % uncertainties…)

General uncertainties of main parameters affecting SOC dynamics. Derived from Gottschalk et al. (2007) and Hastings et al. (2010).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uncertainty in the input</th>
<th>Minimum value</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>± 2 %</td>
<td>Monthly Temp * 0.98</td>
<td>Monthly Temp * 1.02</td>
</tr>
<tr>
<td>Precipitation</td>
<td>± 5 %</td>
<td>Monthly PP * 0.95</td>
<td>Monthly PP * 1.05</td>
</tr>
<tr>
<td>Clay content</td>
<td>± 10 %</td>
<td>Clay * 0.90</td>
<td>Clay * 1.10</td>
</tr>
<tr>
<td>FAO SOC</td>
<td>± 20 %</td>
<td>SOC FAO * 0.8</td>
<td>SOC FAO * 1.2</td>
</tr>
<tr>
<td>C input increase in SSM scenario</td>
<td>± 15 %</td>
<td>C eq * (SSM1 % increase - 15%)</td>
<td>C eq * (SSM % increase + 15%)</td>
</tr>
</tbody>
</table>
Limitations

• Models = simplifications of reality
• No universal models
• Erosion, Clay type? soil nutrients effects?
• pH? Bases?
• aridic soils? Sodic soils? Salt affected?
• red-ox potential; waterlogging, anaerobiosis; organic soils?
• micro and meso fauna effects?
• Soil structure? Soil compaction?
• Among others!!!!

... But we need an initial step...
GSOCseq v1.1

- SOC sequestration (tC/ha/yr) SSM 1-3
- Agricultural lands (croplands + grazing lands)
- 20-year period
- Depth: 0-30 cm
- 1 x 1 km resolution

Relative sequestration rates
tonnes.ha-1.y-1

SSM1 >> SSM3

http://54.229.242.119/GloSIS/
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First results - Global SOC stocks*

*Excluding blank countries (GSOCseq v1.1)

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First results - Annual SOC sequestration

*Excluding blank countries

Previous estimates

<table>
<thead>
<tr>
<th>Source</th>
<th>Seq.rate Pg C.year⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paustian et al (2004)</td>
<td>0.44 - 0.88</td>
</tr>
<tr>
<td>Smith et al (2008)</td>
<td>0.44 - 1.15</td>
</tr>
<tr>
<td>Sommer and Bossio (2014) (croplands+grasslands)</td>
<td>0.37 - 0.74</td>
</tr>
<tr>
<td>Batjes et al (2019)</td>
<td>0.32 - 1.01</td>
</tr>
<tr>
<td>Lal et al (2018) (croplands+grasslands/shrublands)</td>
<td>0.48 – 1.93</td>
</tr>
<tr>
<td>Fuss et al (2018)</td>
<td>0.54 – 1.36</td>
</tr>
</tbody>
</table>
Potential uses - statistics

Which climates, land uses, regions, countries have greater SOC sequestration potential?

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Agricultural soils play an important role in mitigating GHG emissions: emissions could be cut by 31%.

Also work on other mitigation strategies:

*Total Agricultural Emissions from FAOSTAT (2019)
GSOCseq v1.1 Technical Report

- Under review
- To be periodically updated as more national maps are delivered
Useful documentation - Folders

- Technical Specifications and Guidelines (pdf)
- Technical Manual (pdf) (Step by Step)
- Template report (.doc)
- Training Material: SCRIPTS Folders 0-9 - INPUTS - OUTPUTS
- Workshop presentations (.ppt)
- Useful documentation (RothC Win Manual, Soil R Manual; related publications) (.pdf)
Software requirements

• R software - R Studio
• Qgis 3.x
• Google Earth Engine account
R packages

<table>
<thead>
<tr>
<th>Protocol application area</th>
<th>R package</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import and Export Raster data</td>
<td>raster</td>
<td>Hijmans et col. (2020)</td>
</tr>
<tr>
<td></td>
<td>ncdf4</td>
<td>David Pierce (2019)</td>
</tr>
<tr>
<td>Import and Export Vector data</td>
<td>rgdal</td>
<td>Bivand et col. (2019)</td>
</tr>
<tr>
<td>Harmonization</td>
<td>raster</td>
<td>Hijmans et col. (2020)</td>
</tr>
<tr>
<td></td>
<td>rgdal</td>
<td>Bivand et col. (2019)</td>
</tr>
<tr>
<td>Roth C Model</td>
<td>SoilR</td>
<td>Sierra and Mueller (2014)</td>
</tr>
<tr>
<td>Data Manipulation</td>
<td>abind</td>
<td>Plate (2016)</td>
</tr>
<tr>
<td>RothC Model, NPP MIAMI model</td>
<td>soilassessment</td>
<td>Omuto (2020)</td>
</tr>
</tbody>
</table>
Data requirements
(spatial SoilR GSP)
Vector

Country Limits (shapefile polygon)

SRC: EPSG: 4326. WGS84.

Geometry: Multipolygon

Objects: 1

Global Administrative Units Layer (GAUL) 2015
SOIL ORGANIC CARBON (GSOC, latest version)

SRC: EPSG: 4326. WGS84
Resolution: 1x1km
Depth: 0-30 cm
Format: raster, geotiff
Units: t C/ha

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Climate Data

• Monthly 1981-2000:
  Spin UP
  • Precipitation (mm/month) 12 layers (one per month)
  • Air Temperature (°C) 12 layers (one per month)
  • Potential Evapotranspiration (mm/month) 12 layers (one per month)

• MIAMI model
  • Precipitation (mm/year) 20 layers (one per year) or 240 layers (one per month per year) (CRU layer arrangement)
  • Temperature (°C) 20 layers (one per year) or 240 layers (one per month per year) (CRU layer arrangement)
Climate Data

• Monthly From 2001-2018/20
• Warm Up
  • Precipitation (mm/month) 216-240 layers (one per month per year) (CRU layer arrangement)
  • Temperature (°C) 216-240 layers (one per month per year) (CRU layer arrangement)
  • Potential Evapotranspiration (mm/month) 216-240 layers (one per month per year) (CRU layer arrangement)

• Forward
  • Precipitation (mm/month) 12 layers (one per month)
  • Temperature (°C) 12 layers (one per month)
  • Potential Evapotranspiration (mm/month) 12 layers (one per month)
The aim of the Climatic Research Unit (CRU) is to improve scientific understanding of the climate system and its interactions with society. Our research is directed towards answering these key questions:

• How and why does our climate change – past, present and future – and what are the implications?
• How can we quantify, reduce and communicate the uncertainty in the climate information that is developed for society?

Global air temperature
2019 anomaly +0.74°C
(3rd warmest on record)
Additional global climate data set
GEE and R scripts

• TerraClimate is a dataset of monthly climate for global terrestrial surfaces from 1958-2019
• monthly temporal resolution and a ~4-km
• GEE and R scripts to download and prepare the data for you AOI will be provided soon
Climate Data

Temperature
cru_ts4.03.1981.1990.tmp.dat.nc
cru_ts4.03.2001.2010.tmp.dat.nc
cru_ts4.03.2011.2018.tmp.dat.nc

Precipitation
cru_ts4.03.1981.1990.pre.dat.nc
cru_ts4.03.2001.2010.pre.dat.nc
cru_ts4.03.2011.2018.pre.dat.nc

Potential Evapotranspiration
cru_ts4.03.1981.1990.pet.dat.nc
cru_ts4.03.2001.2010.pet.dat.nc
cru_ts4.03.2011.2018.pet.dat.nc

Resolution: 50 km or less (country data)
Format: .nc to geotiff
Units: mm, °C
Soil Data

• CLAY LAYERS (Soilgrids)
• CLYPPT_M_sl1_250m_ll.tif
• CLYPPT_M_sl2_250m_ll.tif
• CLYPPT_M_sl3_250m_ll.tif
• CLYPPT_M_sl4_250m_ll.tif

SRC: EPSG: 4326. WGS84
Resolution: 1x1km
Depth: 0-30 cm
Format: raster, geotiff
Units: %

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Land Use (from Land Cover)

- Global Source: From ESA
- ESA_Land_Cover_11classes_FAO.tif
- (RECLASSIFIED ESA LAND COVER TO 12 classes)
- This file will be provided.
- Spatial Resolution: 300m x 300m

Other preferred National Source
SRC: EPSG: 4326. WGS84
Final Resolution: 1x1km
Format: raster, geotiff
Units: Classes Match FAO classes
<table>
<thead>
<tr>
<th>Value</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Data</td>
</tr>
<tr>
<td>190</td>
<td>Artificial</td>
</tr>
<tr>
<td>10 11 20 30 40</td>
<td>Croplands</td>
</tr>
<tr>
<td>130</td>
<td>Grassland</td>
</tr>
<tr>
<td>50 60 61 62 70 71 72 80 81 82 90 100 110</td>
<td>Tree Covered</td>
</tr>
<tr>
<td>120 121 122</td>
<td>Shrubs Covered</td>
</tr>
<tr>
<td>160 180</td>
<td>Herbaceous vegetation flooded</td>
</tr>
<tr>
<td>170</td>
<td>Mangroves</td>
</tr>
<tr>
<td>150 151 152 153</td>
<td>Sparse Vegetation</td>
</tr>
<tr>
<td>200 201 202</td>
<td>Baresoil</td>
</tr>
<tr>
<td>220</td>
<td>Snow and Glaciers</td>
</tr>
<tr>
<td>210</td>
<td>Waterbodies</td>
</tr>
<tr>
<td>12</td>
<td>Treecrops</td>
</tr>
</tbody>
</table>
Soil/Vegetation cover

- Minimum: 12 layers (one per month) from MODIS NDVI.
- GEE (script)
- Other methods

 SRC: EPSG: 4326.
 WGS84
 Resolution: 1x1km
 Format: raster, geotiff
 Units: 0.6 (covered) to 1.0 (bares soil)
## Summary. Inputs for the 3 Phases

<table>
<thead>
<tr>
<th>Data</th>
<th>Variables</th>
<th>Time series</th>
<th>Units</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Climatic data</strong></td>
<td>Monthly air temperature</td>
<td>1980-2000, 2001-2020 (or until last year available)</td>
<td>°C</td>
<td>Raster</td>
</tr>
<tr>
<td></td>
<td>Monthly evapotranspiration (Penman-Monteith)</td>
<td>1980-2000; 2001-2020 (or until last year available)</td>
<td>mm</td>
<td>Raster</td>
</tr>
<tr>
<td></td>
<td>Monthly precipitation + irrigation</td>
<td>1980-2000; 2001-2020 (or until last year available)</td>
<td>mm</td>
<td>Raster</td>
</tr>
<tr>
<td><strong>Soil data</strong></td>
<td>Topsoil clay content (0-30 cm)</td>
<td>-</td>
<td>%</td>
<td>Raster</td>
</tr>
<tr>
<td></td>
<td>Current Soil organic carbon stocks (0-30 cm)</td>
<td>Latest version of national FAO-GSOC map</td>
<td>tC ha⁻¹</td>
<td>Raster</td>
</tr>
<tr>
<td><strong>Land use/cover</strong></td>
<td>Predominant land use/cover, re-classified into:</td>
<td>Minimum: representative 2000-2020 (or last year available)</td>
<td>1-11</td>
<td>Raster</td>
</tr>
<tr>
<td></td>
<td>Minimum: 4 default classes required by model:</td>
<td>Optimum: annual land use 2000 to 2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>agricultural crops, grassland/shrubland/savannas; forests; others</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optimum: 11 classes defined in the FAO Global Land Cover - SHARE (GLC-SHARE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monthly vegetation cover. Obtained from national statistics/local expert</td>
<td>Minimum: average 2015-2020 (or last year available)</td>
<td>0-1</td>
<td>Raster</td>
</tr>
<tr>
<td></td>
<td>knowledge; or derived from NDVI or spectral indexes (see section 3.3.4)</td>
<td>Optimum: monthly soil cover 2000 to 2020</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Scripts - Sequence

promoting sustainable soil management for all
<table>
<thead>
<tr>
<th>Type of Layer</th>
<th>Script</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOC layer</td>
<td>0. R- Script number 0</td>
<td>Cut the soc layer by the area of interest polygon</td>
</tr>
<tr>
<td>Climate layers</td>
<td>1. R- Script number 1</td>
<td>Rearrangement of climate layers (CRU layers from .ncd to .tif)</td>
</tr>
<tr>
<td></td>
<td>2. R- Script number 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. R- Script number 3</td>
<td></td>
</tr>
<tr>
<td>NPP layers</td>
<td>5. R- Script number 5</td>
<td>Creation of NPP layers</td>
</tr>
<tr>
<td>Vegetation Cover (VC)</td>
<td>6. GEE Script number 6 (Google Earth Engine)</td>
<td>Creation of VC layers</td>
</tr>
<tr>
<td></td>
<td>7. R- Script number 7</td>
<td></td>
</tr>
<tr>
<td>Clay layers</td>
<td>8. R-Script number 8</td>
<td>Obtaining clay contents 0-30 cm from different depths (ISRIC)</td>
</tr>
<tr>
<td>Land Use layer</td>
<td>9. R-Script number 9</td>
<td>Re-classification into FAO land cover classes</td>
</tr>
<tr>
<td>STACK for SPIN UP</td>
<td>10. R-Script number 10</td>
<td>Stack input data layers for the spin up phase</td>
</tr>
<tr>
<td>STACK for WARM UP</td>
<td>11. R-Script number 11</td>
<td>Stack input data layers for the warm up phase</td>
</tr>
<tr>
<td>STACK for FORWARD</td>
<td>12. R-Script number 12</td>
<td>Stack input data layers for the forward phase</td>
</tr>
<tr>
<td>Target points</td>
<td>13. Qgis model script</td>
<td>Creation of target points</td>
</tr>
<tr>
<td>SPIN UP</td>
<td>14. R- Script number 13</td>
<td>Run long spin up phase</td>
</tr>
<tr>
<td>WARM UP</td>
<td>15. R- Script number 14</td>
<td>Run warm up phase</td>
</tr>
<tr>
<td>FORWARD</td>
<td>16. R- Script number 15</td>
<td>Run forward phase</td>
</tr>
<tr>
<td>POINTS TO RASTER</td>
<td>17. R- Script number 16</td>
<td>Rasterize points</td>
</tr>
</tbody>
</table>
Folders

script: promoting sustainable soil management for all
DIRECTORY : INPUTS

promoting sustainable soil management for all
DIRECTORY : OUTPUTS (MODEL)

promoting sustainable soil management for all
Step 1: Data preparation
Soc FAO : master layer

0_SOC_MAP_AOI.R

**OBJECTIVE:** CROP SOC MAP BY USING COUNTRY POLYGON OR REGION OF INTERES

UNIT: [tn/ha]
Harmonization of Climate Layers (CRU)

OBJETIVE: ARRANGE CLIMATE FILES (CRU FORMAT) TO BE USED IN THE MODELING PHASES

Units: [mm/month] [°C]
**OBJETIVE**: Estimate annual NPP (using MIAMI Model) for the 1981-2000 period. Year to year NPP is estimated and then averaged.
OBJECTIVE: Estimate clay % 0-30 cm depth using weighted average (ISRIC Clay layers)

Unit: %
LAND USE

OBJECTIVE: RE-CLASSIFY ESA (EUROPEAN SPACE AGENCY) COVER CLASSES TO FAO LAND USE CLASSES.
OBJECTIVE: Generate a stack of 12 layers, one for each month that represents vegetation cover for each pixel.

• We will estimate Google Earth Engine for each pixel, as the number of images with vegetation from total images of a specified time series (assuming NDVI higher > 0.3 threshold)
• We will get a probability from 0 to 1, (being 0 never covered and 1 always covered)
• These values are then re-escalated to the vegetation cover factor (0.6 = covered; 1 = bare soil)

Final Unit: 0.6-1.0 promoting sustainable soil management for all
Vegetation cover from Google Earth Engine

<table>
<thead>
<tr>
<th>MOD13A2 v006 MODIS/Terra Vegetation Indices 16-Day L3 Global 1 km SIN Grid</th>
<th>0.7</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

365/16 ≈ 22 Layers per year  
22/12 ≈ 2 Layers per month

Total images = \(\sim 2\) Layers per month x years of interest

\[
P_{\text{veg}} = \frac{\text{Number of images } \text{NDVI} > 0.6}{\text{Total images}}
\]

<table>
<thead>
<tr>
<th>Dec 2015</th>
<th>Dec 2016</th>
<th>Dec 2017</th>
<th>Dec 2018</th>
<th>Dec 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Vegetation cover layers (from GEE)

- Veg_COVER_NDVI_1km
- MOD13A2 NDVI product
OBJECTIVE: GENERATE STACKS OF INPUT DATA LAYERS (USING GSOC FAO 1KM AS A MASTER LAYER) TO BE USED IN EACH MODELING PHASE: SPIN UP- WARM UP – FORWARD.

FOR THE WARM UP PHASE, CLIMATE LAYERS ARE NOT INCLUDED IN THE STACK DUE TO FILE SIZE RESTRICTIONS (NEAR 700 LAYERS).
OBJECTIVE: GENERATE TARGET POINTS WHERE THE MODEL IS TO BE RUN

SELECT ONLY LAND USES OF INTERESTS (AVOID WATER BODIES, NATIVE VEGETATION, FORESTS, DESSERT AREAS... WHERE NO MANAGEMENT IS TO BE IMPLEMENTED)

CAN BE MODIFIED DEPENDING ON COUNTRY INTERESTS (Eg. restoration of native vegetation)
Step 2 : Running the model
Running the Roth C - SoilR

**SPIN UP:** The objective is to estimate C input levels to reach FAO GSOCmap SOC stocks. Additionally, to estimate initial SOC stocks of each pool.

**WARM UP:** The objective is to C inputs and SOC stocks using monthly data from the last 20 years (climate- NPP - land use (optional)).

**FORWARD:** The objective is to project SOC stocks per pixel and estimate the uncertainty of that prediction.
Step 3 : From Points to Rasters
FROM POINTS TO RASTERS

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OBJECTIVE:
MODELING OUTPUT WILL BE A ‘POINT’ VECTOR FILE (1 POINT PER PIXEL), WITH INFORMATION ABOUT THE THREE SCENARIOS AND THE BASE SCENARIO (BAU).

IT WILL ALSO CONTAIN INFORMATION ON THE UNCERTAINTY OF THE SIMULATED DATA. THESE VALUES ARE SAVED IN A TABLE ATTACHED TO THOSE POINTS (ESRI SHAPEFILE FORMAT).

THIS LAST STEP WILL TRANSFORM THESE POINTS TO RASTER FILES, ONE FOR EACH TARGET MAP.
PRO SeitS
Final SOC Stocks (tC/ha) & Uncertainties (%)
ABSOLUTE DIFFERENCES (SCENARIO – T0)
In tC/ha

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ABSOLUTE RATES : ABS DIF./20
In tC/ha/year
RELATIVE DIFFERENCES: (SCENARIO – BAU)

In tC/ha

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RELATIVE RATES : REL. DIF./ 20 In tC/ha/year

promoting sustainable soil management for all
Thank You

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lucianoeliasdipaolo@gmail.com