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SOC pool – scientific understanding, dynamics, sampling, measurements, GHG reporting

Session 2: Soil Organic Carbon (SOC) in Agriculture, Forestry and Other Land-Use (AFOLU) sector of national GHG inventories

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Soil organic carbon (SOC) pool

- Soil plays an important role in the global carbon cycle.
- The carbon stock of soil equals some 1 500 Pg in the topmost 1 m soil layer.
- Globally, the soil carbon stock is nearly three times the amount in the above-ground biomass and about twice as large as the carbon stock of the atmosphere.
- Changes in soil carbon result from an imbalance between the carbon fluxes into and out of the soil.
- Increments in plant productivity and input of plant residues to soil have an increasing effect on soil carbon stock, whereas more favorable conditions for decomposition have a decreasing effect.
- Land-use change may induce quite rapid changes in soil carbon as a result of altered carbon input to the soil or decomposition conditions or both.

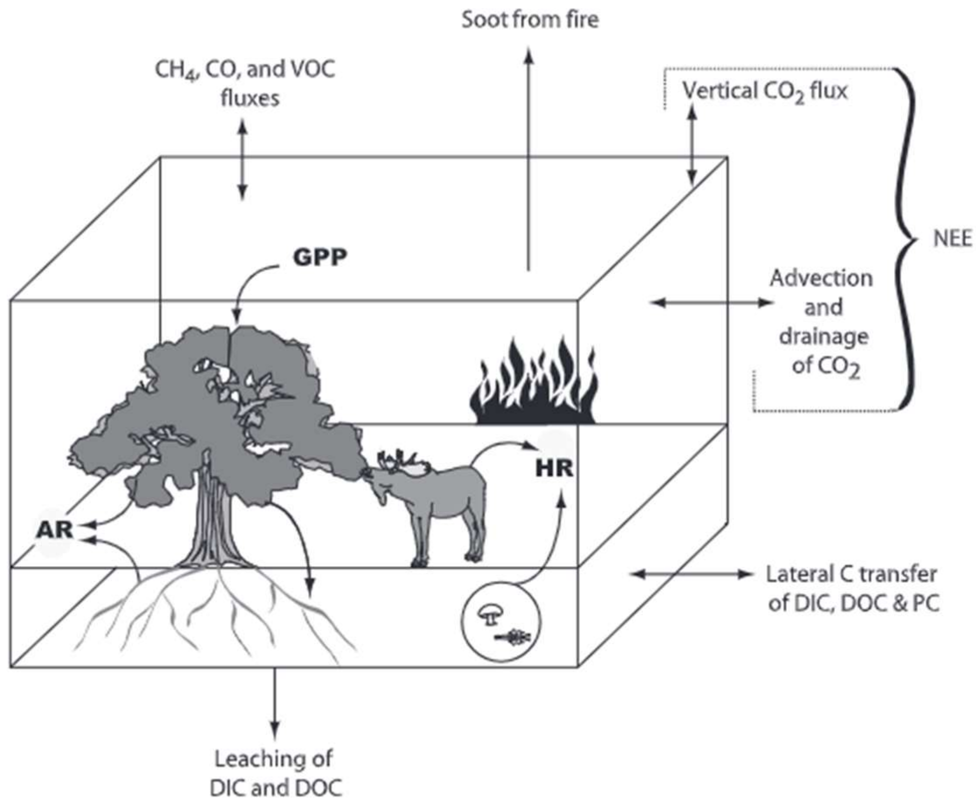
Ecosystem carbon dynamics – scientific understanding

Ecosystem C fluxes

Fluxes that determine Net Ecosystem Production (NEP) are shown in bold:
GPP= gross primary production

AR= autotrophic respiration

HR= heterotrophic respiration



Source: Chapin III et al. https://doi.org/10.1111/j.1365-2745.2009.01529.x

Soil organic carbon (SOC) dynamics – scientific understanding

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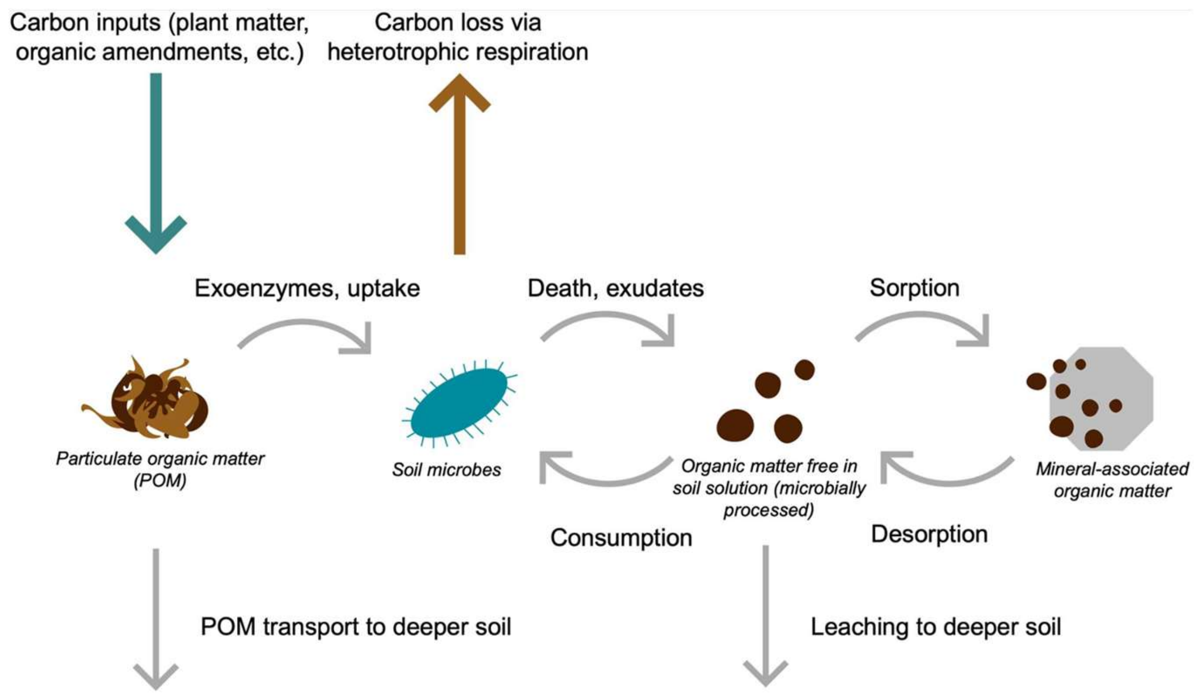
- Soil carbon flows

Carbon enters soil mainly via plant inputs (blue arrow) and is lost via heterotrophic respiration (brown arrow).

Plant C inputs are the precursor to particulate organic matter (POM), which can be depolymerized by microbes and taken up into biomass, or transported deeper into the soil profile as particulate matter.

Microbial depolymerization, exudation, and turnover releases microbially processed C, which is free in soil solution and can sorb onto mineral surfaces to produce mineral-associated organic matter (MAOM). Mineral-associated organic matter can de-sorb from mineral surfaces and taken back up into microbial biomass or be transported to deeper soil profiles via leaching.

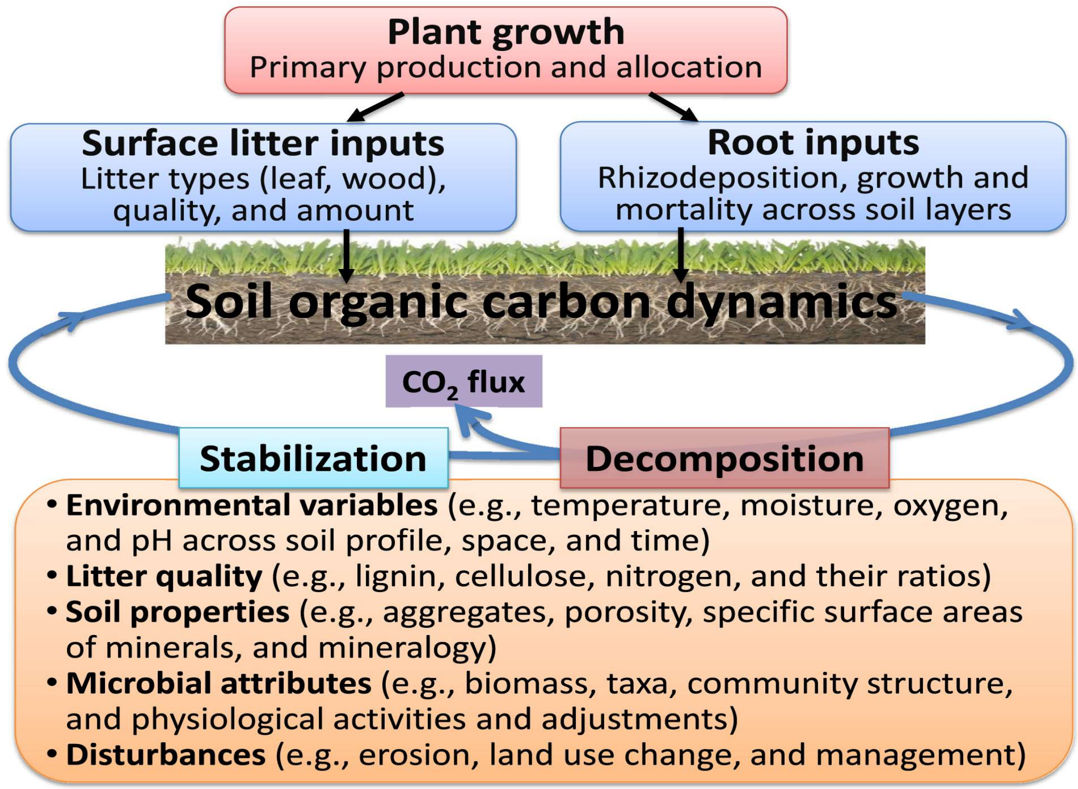
Over time, these cycling processes result in the movement of both microbially processed C and POM into increasingly deeper soil horizons.



Source: Dynarski et al. 2020. https://doi.org/10.3389/fenvs.2020.514701

SOC dynamics – scientific understanding

- Major processes and factors that determine SOC dynamics.
- C input and SOC transformations are regulated by environmental and biological variables



Source: Luo et al. 2015 https://doi.org/10.1002/2015GB005239

Challenges in the monitoring changes in soil C

- Challenging task to detect a relatively small change in a large stock.
- Large spatial variation in soil properties -> a large number of samples needed to obtain reliable estimate of the average stock and stock change.
- Mäkipää et al. 2012

Designing a soil carbon survey

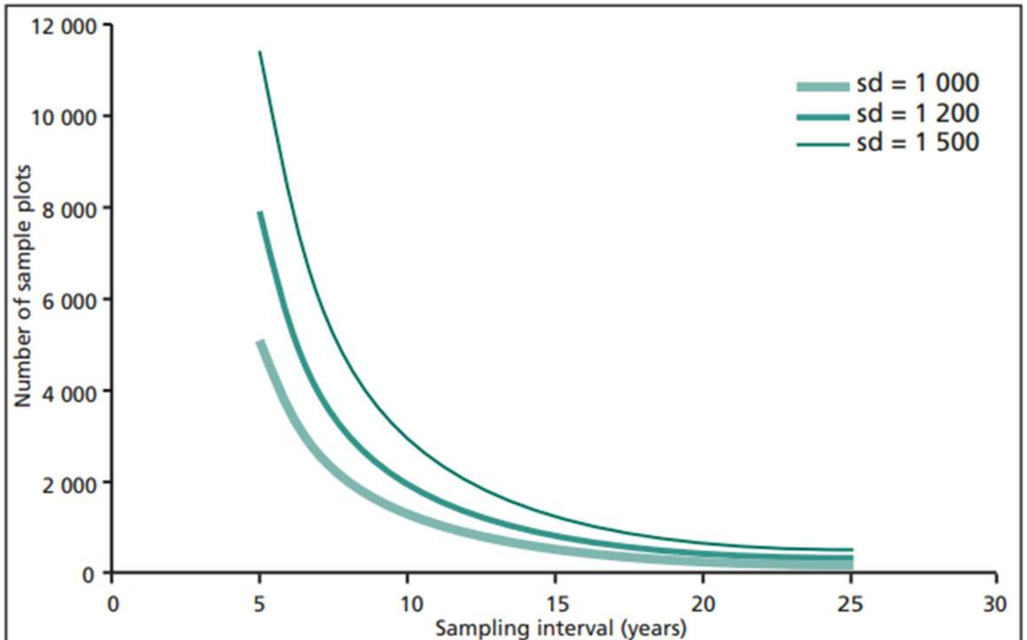
The objective of the nationwide soil carbon inventory is to provide unbiased estimates of the soil carbon stock and stock changes. In designing soil carbon monitoring, relevant issues to be considered are:

- sampling intensity (number of study sites) and rules to locate the study sites
- sampling interval (e.g. decadal or five-year interval)
- soil layers to be studied (2006 IPCC guidelines recommend a default 0–30 cm layer)
- location of sample points and their number at the study sites

It is necessary to know how many samples need to be taken to estimate a statistically significant change. Appropriate sampling intensity (sample size) and sampling interval (time between consecutive measurements) can be designed after collecting information on between-site variation and estimation of the rate of potential change (that can be based on modelling).

How large sample size required in national soil survey

- Depends on variation of measured stock and sampling interval.
- Example: Sample size required with different sampling intervals calculated on the assumption that the change to be detected is 11 g C m^{-2} per year. Standard deviation (sd) of measured carbon stock was assumed to be 1 000 g C m^{-2}. *Larger values (1 250 and 1 500 g C m^{-2}) were applied to show the sensitivity of the results to this assumption.*



Source: Mäkipää *et al.*, 2008

Model-based soil carbon monitoring system

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Four components:

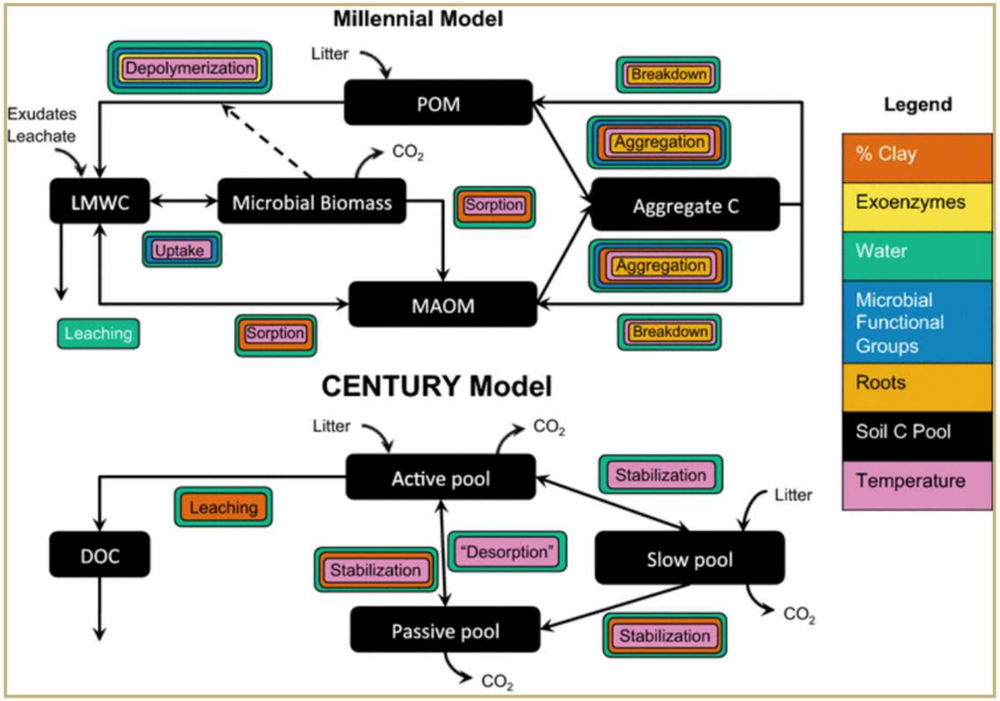
1. Input information to a soil carbon model
2. Reliability control of modelling soil carbon cycle
3. Simulation of soil carbon cycle
4. Results of soil carbon budget

Empirical data required for:

1. Input information to a soil carbon model
2. Validity testing
3. Model calibration (if needed)
4. Model development

Model-based soil carbon monitoring system

- Soil carbon models typically box models where organic matter is the input (litter from vegetation)
- Where decomposition is driven by temperature and moisture
- Also litter quality (decomposability) affects dynamics



Model-based approach – case Ethiopia

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- Estimating soil carbon stock for forests in Ethiopia
  - Based on the soil sampling (2017-2018, a sub-set of forest inventory plots)
  - Based on the modelling (Yasso07 and CENTURY)

- Evaluating how forest use affects soil C stocks in future
  - Using MODIS NPP product for 2000-2010 to estimate litter input to soils
  - Using variable wood extraction rates to study impacts to soil C stocks

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RESEARCH ARTICLE

WILEY

Soil carbon stocks in Ethiopian forests and estimations of their future development under different forest use scenarios

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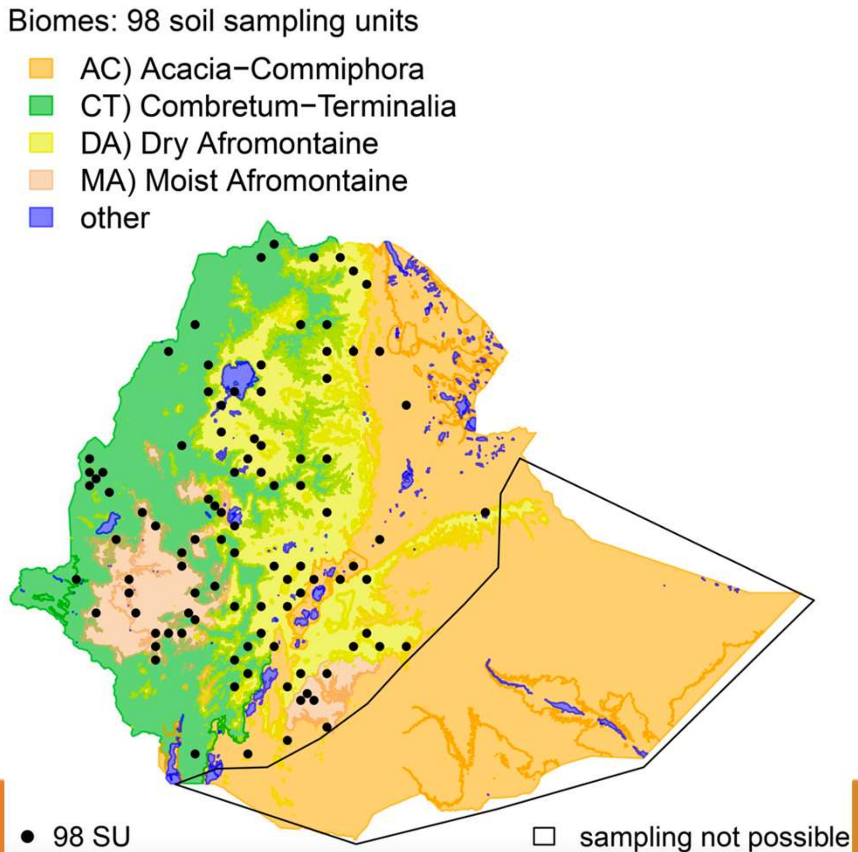
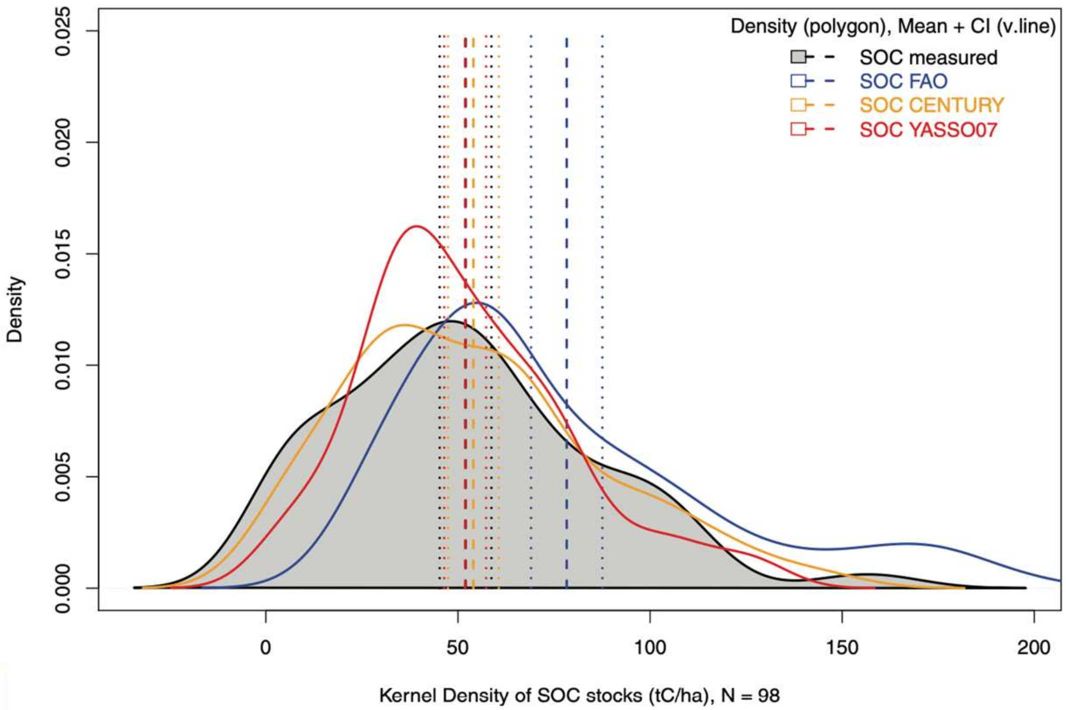
Model-based approach – case Ethiopia

Measurements

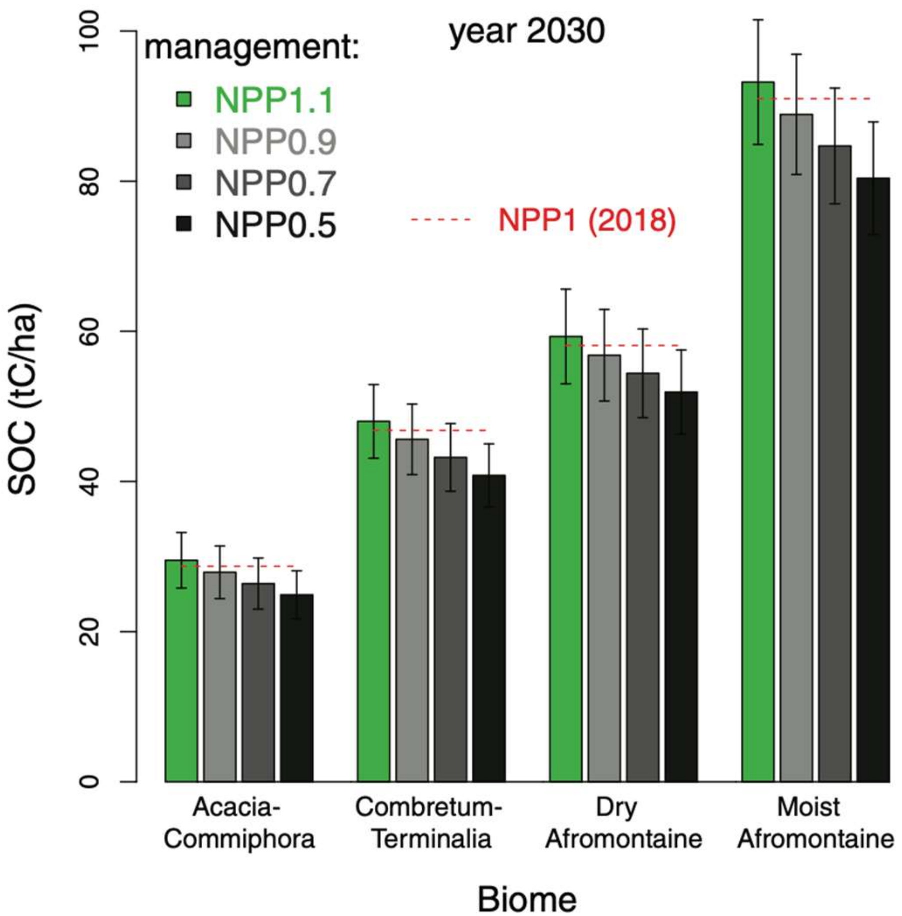


Measurements vs. models vs. FAO GSOC



Model-based approach – case Ethiopia

- Current soil C stock estimates illustrated with red line
- Intensifying forest use and using more net primary production (NPP) to other uses results smaller soil C stocks



Measurements

Soil carbon stock and soil properties

Soil CO_2, CH_4 and N_2O fluxes

GHG reporting of LULUCF sector under the UNFCCC

- Countries must estimate and report GHG emissions and removals, including changes in carbon stocks in all five pools
  - aboveground biomass
  - belowground biomass
  - dead wood
  - litter and
  - soil carbon

according to the IPCC Good Practice Guidance.

- GHG inventory methodology applied also in the reporting of the NDC of the Paris Agreement.

IPCC Good Practice Guidance

- IPCC has developed standard methods for estimating soil organic carbon stocks and stock changes
- These methods are characterized by flexibility, ranging from Tier 1-3
  - Tier 1 default method with fixed default values (area x emission factor),
  - Tier 2 methods that incorporate local information to estimate carbon stock changes,
  - Tier 3 more advanced modelling and measurement based methods. Since measuring soil carbon stock changes is a laborious and expensive undertaking, soil carbon modelling is often used as an alternative or a complement to repeated soil carbon inventories to estimate and report the changes in soil carbon stock.

Developing a reporting system for soils under UNFCCC

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- Often countries have measurements of soil C stock, not soil C change
  - In this case one option is to adopt a simple soil C model and calibrate that against those soil C measurements
  - One can also repeat existing soil C samling to get the change in soil C
- Model can be improved and tested with additional soil C data collection
- Target data collection to areas and biomes where most of the changes occur
- Note that intensification of forest use usually results soil C loss, while extensification can lead to soil C accumulation.

Conclusions

- GHG inventories are under constant improvement and one has to start from somewhere
- It is important to build capacity for soil C monitoring and modelling
  - GHG inventories
  - Soil productivity and resilience

- It should not be about models vs. empirical data, as both are needed
  - Data brings the reality check for models
  - While models allow future scenarios, and asking “what if … ”

Thank you
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