GrassNet Summer School 2010

Soil Organic Matter
Relevance for climate change studies in grassland ecosystems

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Content

- Introduction and definitions
- SOM in grassland systems
- Pools, fractions and how to get the hands on them.
- Stabilisation of SOM
- Conclusions

Introduction and definitions

- Soil Organic Matter (SOM)
  - All dead organic matter in the soil (OM on the soil = litter, has to be incorporated to be called SOM)
- Soil Organic Carbon (SOC)
  - C in the SOM, approximately 50% of SOM (Polysaccharides ~ 40%, lipids ~70%)
- Decomposition
  - Disintegration of OM in the soil via biological, chemical and physical processes
  - Humification: Formation of new substances out of fragments during decomposition
  - Mineralisation: Complete degradation of OM to CO_2 and H_2O
  - Quantity and quality of SOM change during these processes
- Climate change (view of a soil scientist)
  - Changes quantity and quality of biomass production
  - Changes climate in the soil
  - SOM is discussed as a sink and/or source for atmospheric CO_2 with the potential to mitigate the anthropogenic global warming

SOM in grassland systems

- Diagnostic horizon of grassland soils = Mollic horizon
  - well-structured
  - dark-coloured
  - high base saturation
  - Moderate to high organic matter content

  => Phaeozem, Chernozem, Kastanozem (sorted with decreasing soil water content)
- Why does this kind of horizon form?
  - Relatively high biomass production in summer
  - Retarded decomposition in hot and dry summer
  - No decomposition in cold winter
  - High bioturbation incorporates OM (deep-diging in winter)

  => Accumulation of organic matter in a thick organic matter rich A-horizon (Mollic horizon).
- (Secondary) Carbonates may occur due to ascending water movement

IUSS Working group WRB (2006): World reference base of soil ressources, FAO, Rome.

Significance of SOM in grassland systems

- SOM is important in grassland systems because...
  - Contain nutrients (C, H, N, O, P, S, Ca, Mg, Cu, Mn, Zn, Al, Fe…)
  - Nutrient storage via adsorption
  - Structures the soil material (of great importance in aeolian landscapes as e.g. asian steppe ecosystem when thinking of erosion/deposition processes)
  - Positively affects soil temperature, soil moisture, land-use,
  - Prevent decalcification (keep pH)
- Grassland SOM and global change
  - CO2 is sequestered by plants
  - Plants die and become OM
  - OM is incorporated into the soil
  - Grasslands cover large areas
  - Grassland systems and especially soils can store SOM for long periods of time (up to millennia)

  => Atmospheric C is removed from atmosphere for long periods of time

Ways to increase the amount of SOM in grassland soils and to save the climate?

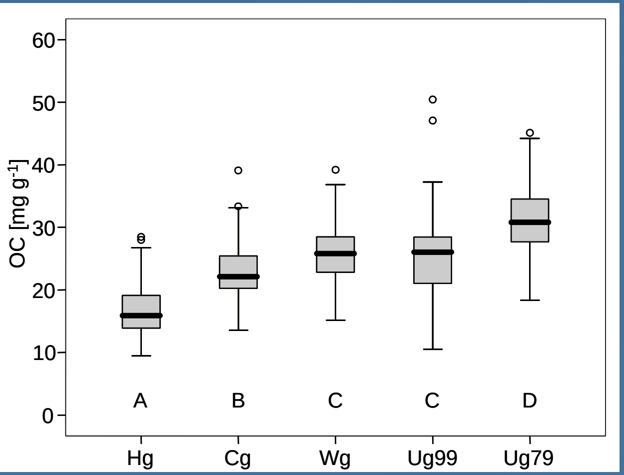
SOM determination

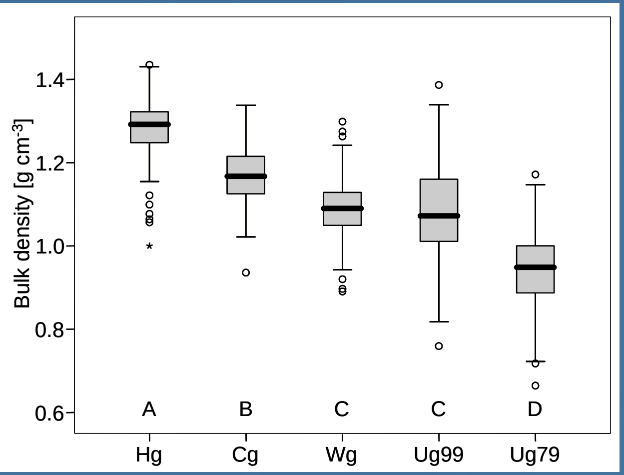
- State of the art: Determination by dry combustion
  - Relative concentration of C in a given mass (total C)
  - “Old” wet chemical methods are suitable but have to be corrected if data is to be compared to other studies.
- If different management systems or climatic conditions are to be compared, absolute masses or volumes have to be considered. Concentrations do not give stocks!
  - Bulk density, stone content and thickness of horizons have to be assessed precisely.
- Grassland soils may contain inorganic C (carbonates) due to ascending groundwater
  - C has to be measured 2 times, in an unchanged sample (total C) and after heating the sample to 550°C (inorganic C).
  - Organic C is calculated as the difference between both.

OC in grassland systems: Impact of grazing intensity

MAGIM (Project P1: Grazing and SOM)

- Five differently grazed plots to assess the benefits of grazing reduction and exclusion on grassland systems.
  - Hg: Heavily grazed
  - Cg: Continuously grazed
  - Wg: Grazed during winter
  - Ug99: Ungrazed since 1999
  - Ug79: Ungrazed since 1979
- 125 positions in each plot (Bulk density, C, N and S concentration, pH, ^{13}C)





Steffens et al. (2008): Grazing effects on soil chemical and physical properties in a semi-arid steppe of Inner Mongolia (P.R. China). Geoderma, 143: 63–72.

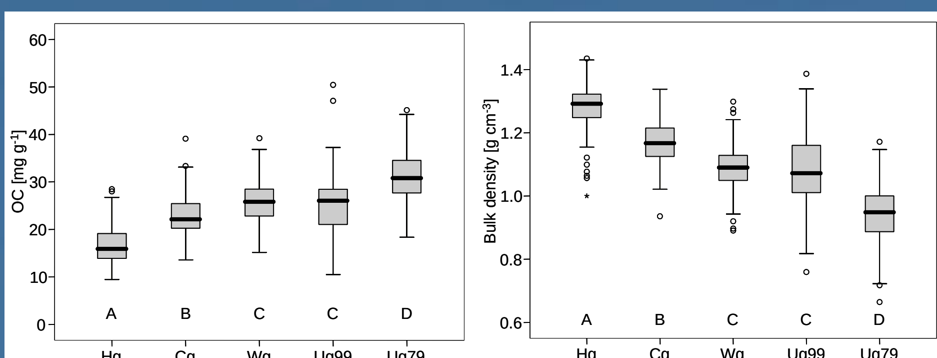
Grazing reduction and exclusion increase SOM (and reduce bulk density)

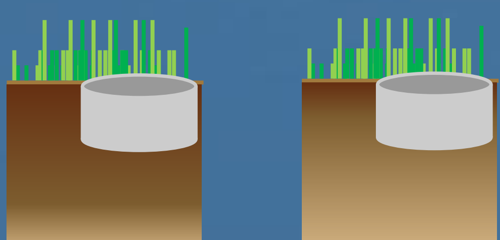
=> Bright future for sequestration of atmospheric C in grassland systems!?

OC in grassland systems: Elemental stocks

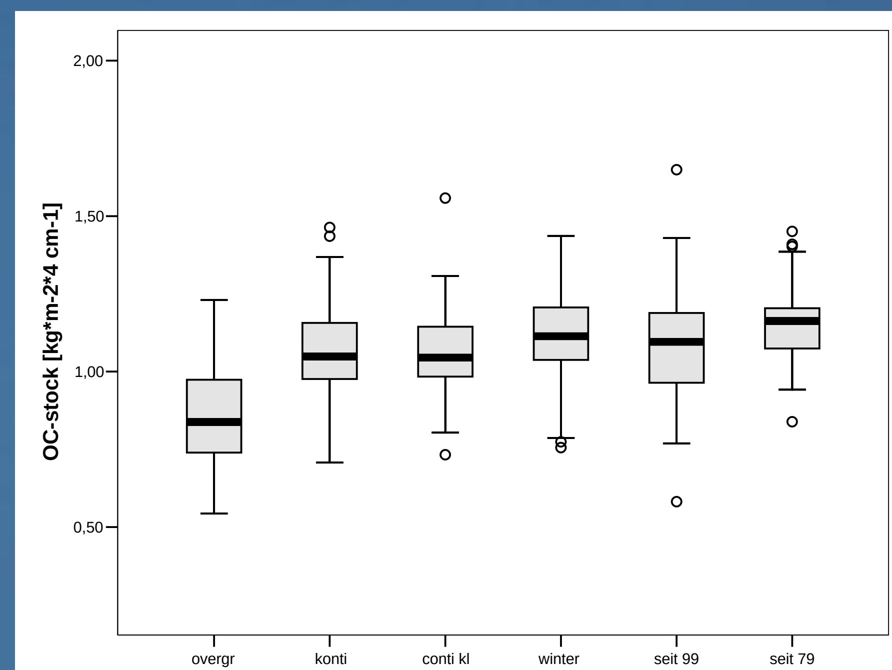
- Reconsidering the slide "SOM determination"
- Land use change can change bulk density and thickness of horizons
  - Higher bulk densities equalised the decrease in elemental concentration producing similar stocks. In reality, thickness of horizon changed! (Additional OM decreases bulk density and increases thickness! Hoof action in grazed plots decreases thickness and increases bulk density)
  - Equivalent masses (Ellert and Bettany, 1997) or corrected sampling depths have to be considered to correct the C masses of different treatments.

> "If different management systems or climatic conditions are to be compared, absolute masses or volumes have to be considered. Concentrations do not give stocks!
> - Bulk density, stone content and thickness of horizons have to be assessed precisely."





Corrected sampling depths:
- Ug99: 3.47 cm
- Wg: 3.45 cm
- Cg: 3.23 cm
- Hg: 2.98

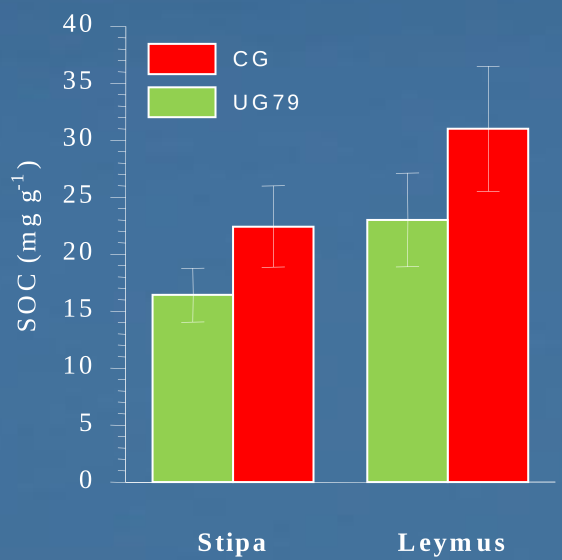


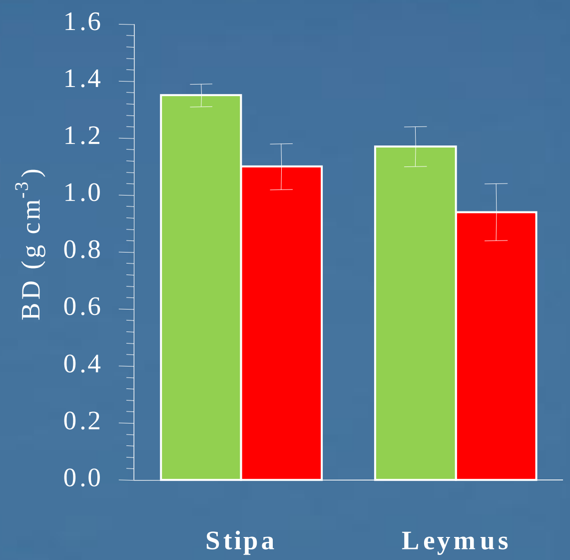
Ellert and Bettany (1995): Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Canadian Journal of Soil Science 75 (4): 529–538.

OC in grassland systems: Impact of plant community

- External factors can change soil and SOM on small scales
- MAGIM II plots were analysed with similar methods
    - Approximately 4 km NW of MAGIM I plots
    - Similar climate, exposition, soil and management
    - Different geology (MAGIM I: Aeolian deposits above acid volcanic rocks; MAGIM II: Aeolian deposits above basic volcanic rocks, relatively drier)

=> Slightly different plant community (MAGIM I: Leymus chinensis dominated; MAGIM II: Stipa grandis dominated)





Slight differences can already affect the results and the message!

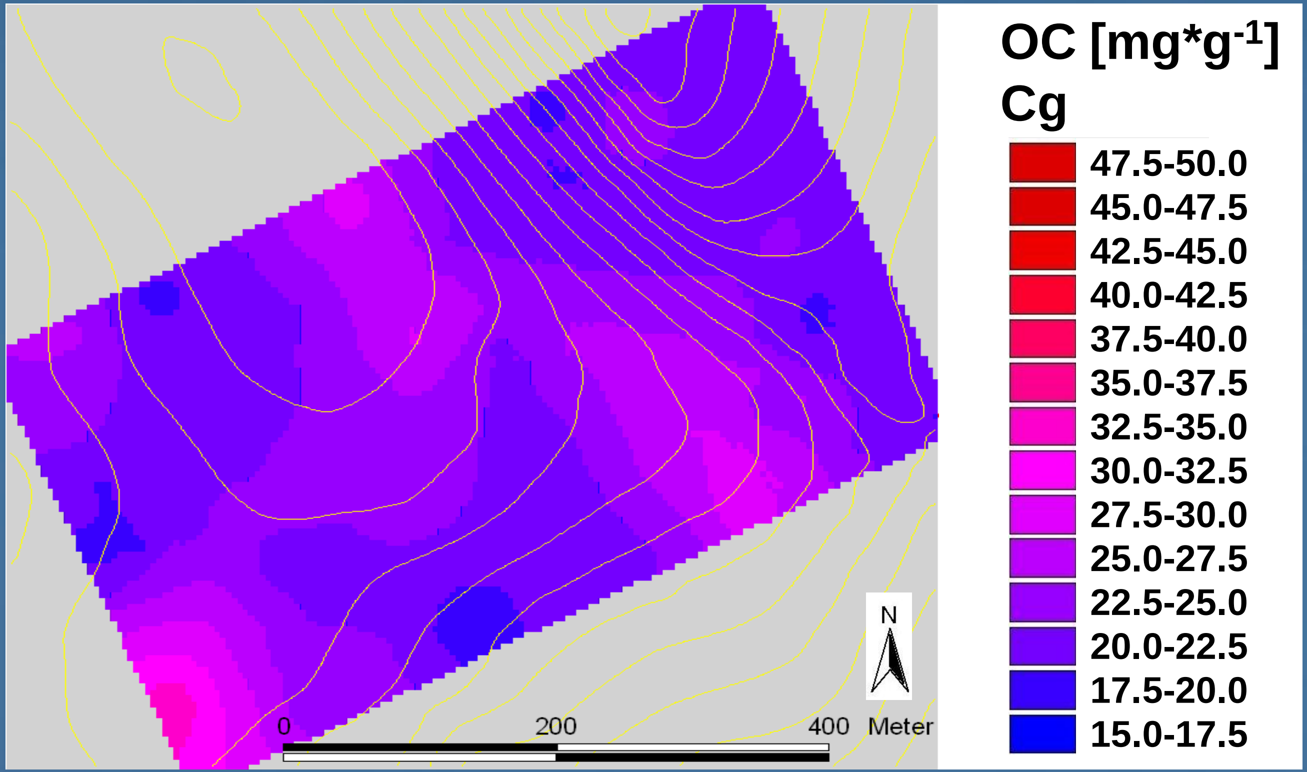
Wiesmeier et al. (2009): Degradation and small-scale spatial homogenization of topsoils in intensively-grazed steppes of Northern China.- Soil Tillage Research, 104 (2): 299-310.

OC in grassland systems: Spatial distribution

- Commonly, different management systems or climatic conditions are compared with mean values and powerful statistical tools.
- Each plot is characterised with a mean and standard deviation.
- But soils and also SOM exhibit a heterogeneous spatial distribution across many spatial scales ranging from single aggregates across the pit and plot to the continental scale.

Spatial distribution - plot scale

- Five plots with different grazing systems were sampled with regular, orthogonal grids and analysed with geostatistics
  - Each consisting of 125 sampling points (spacing 50 m, small-scale 10 m), sampling depth 4 cm
- On the plot scale erosion/deposition processes were responsible for spatial pattern of all analysed parameters.
- Grazing intensity only amplified these processes



- Statistical tools are powerful for elucidating effects - but just give mean values and only answer the questions asked.
- Strong spatial heterogeneities on the plot scale

Steffens, et al. (2009): Spatial variability of topsoil and vegetation in a grazed steppe ecosystem in Inner Mongolia (P.R. China). Journal of Plant Nutrition and Soil Science, 172.

Spatial distribution - profile scale

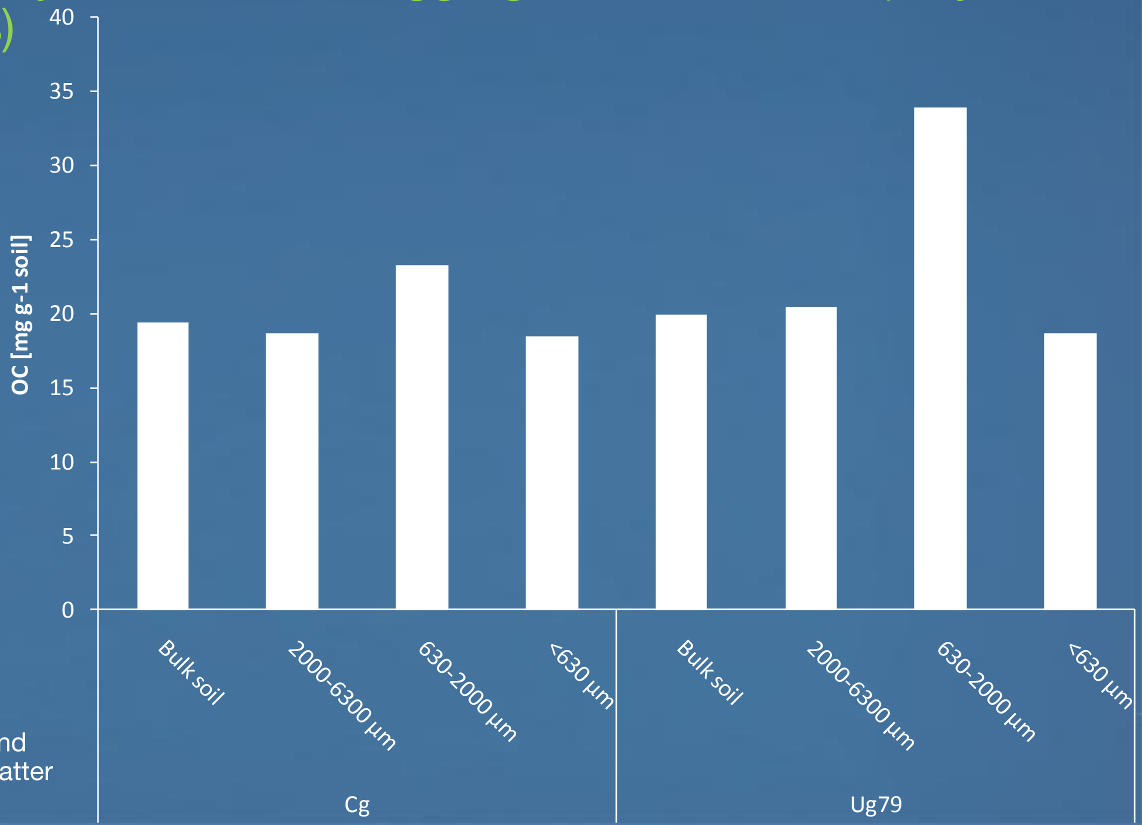
- MAGIM II showed high spatial variability on the plant scale
  - Accumulation of OM under the each plant
  - Deposition of windblown OM-rich fine material at each plant
  - -> Higher water content, higher biomass production
  - => Island of fertility (self-amplifying)
- Beside the horizontal distribution soils and SOM also show a vertical heterogeneity
- Most authors assume the first 5 to 10 cm to contain the largest amount of SOM in grassland systems.
- This layer is mainly affected by land-use and climate change.
- Deeper soil layers do not contain large amounts and are safe against external effects

- Strong heterogeneities on the pit scale
- Topsoil layers are predominately affected by land-use and climate change!?

Spatial distribution - aggregate scale

- Most studies use bulk samples sieved to <2 mm
- But soil consists of primary particles connected to each other forming aggregates
- Differently sized aggregates have different associated processes and characteristics (Porosity, water content, temperature, biology...)
- MAGIM I pit samples were gently sieved to four aggregate size classes (only three used for further analyses)
  - Big aggregates >6300 µm
  - Coarse aggregates >2000 µm
  - Medium aggregates >630 µm
  - Small aggregates <630 µm

=> Clearly different SOM content



Spatial heterogeneities of SOM on the aggregate scale

Steffens et al. (2009): Alteration of soil organic matter pools and aggregation in semi-arid steppe topsoils as driven by organic matter input. European Journal of Soil Science, 60(2): 198-212.

SOM fractions

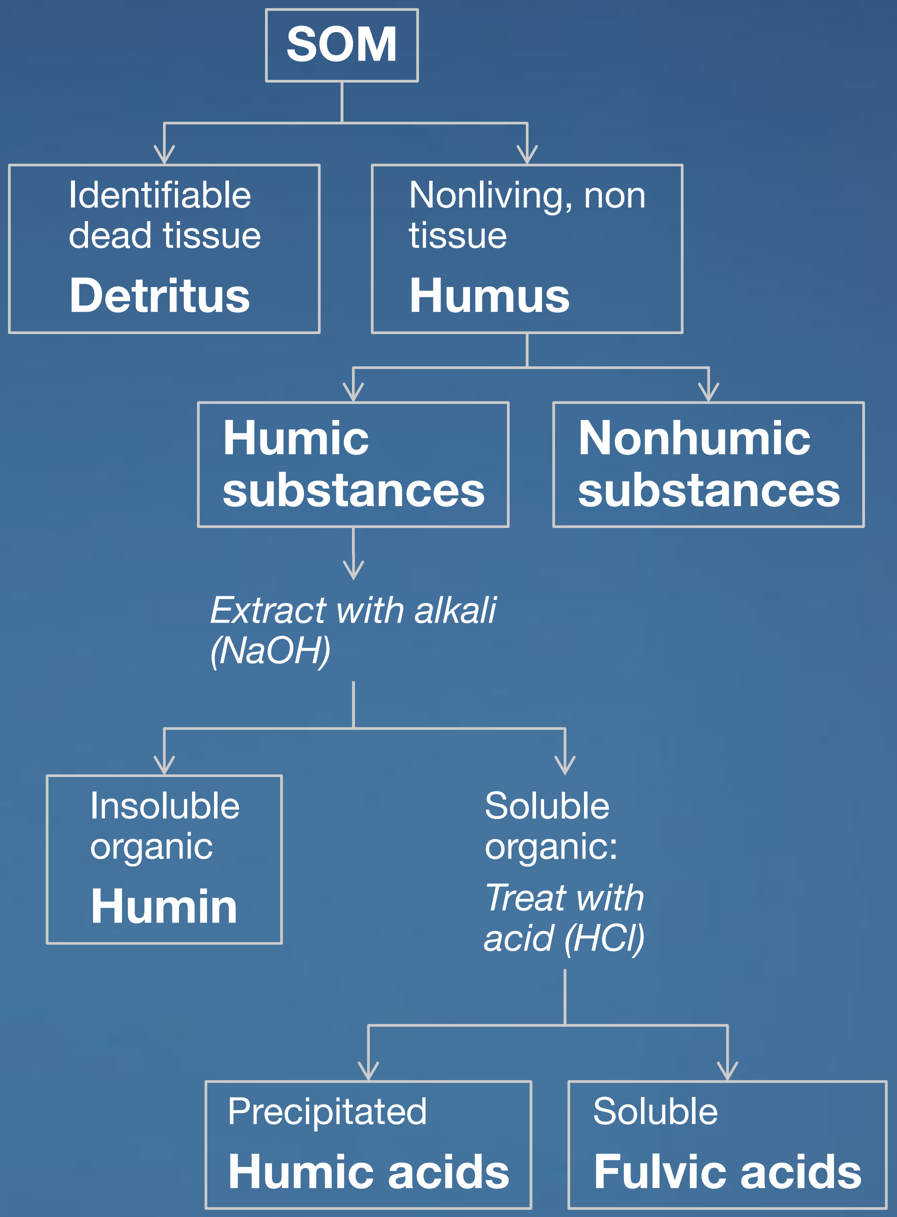
- Pools: Conceptional (fictional) classes of homogeneous organic matter
  - Homogeneous in physical, chemical and biological aspects
  - But clearly different from each other
- Fractions: Functional (“real”) classes of organic matter
  - Separated in laboratory with physical or chemical methods
  - Classical method: Chemical fractionation

Chemical fractionation

- Classical approach of OM extraction
  - Extracts ~80% of humic substances
  - Also living organisms are extracted
  - Extractants change quality of the fractions
  - Fractions are complex and do not correspond to conceptional pools

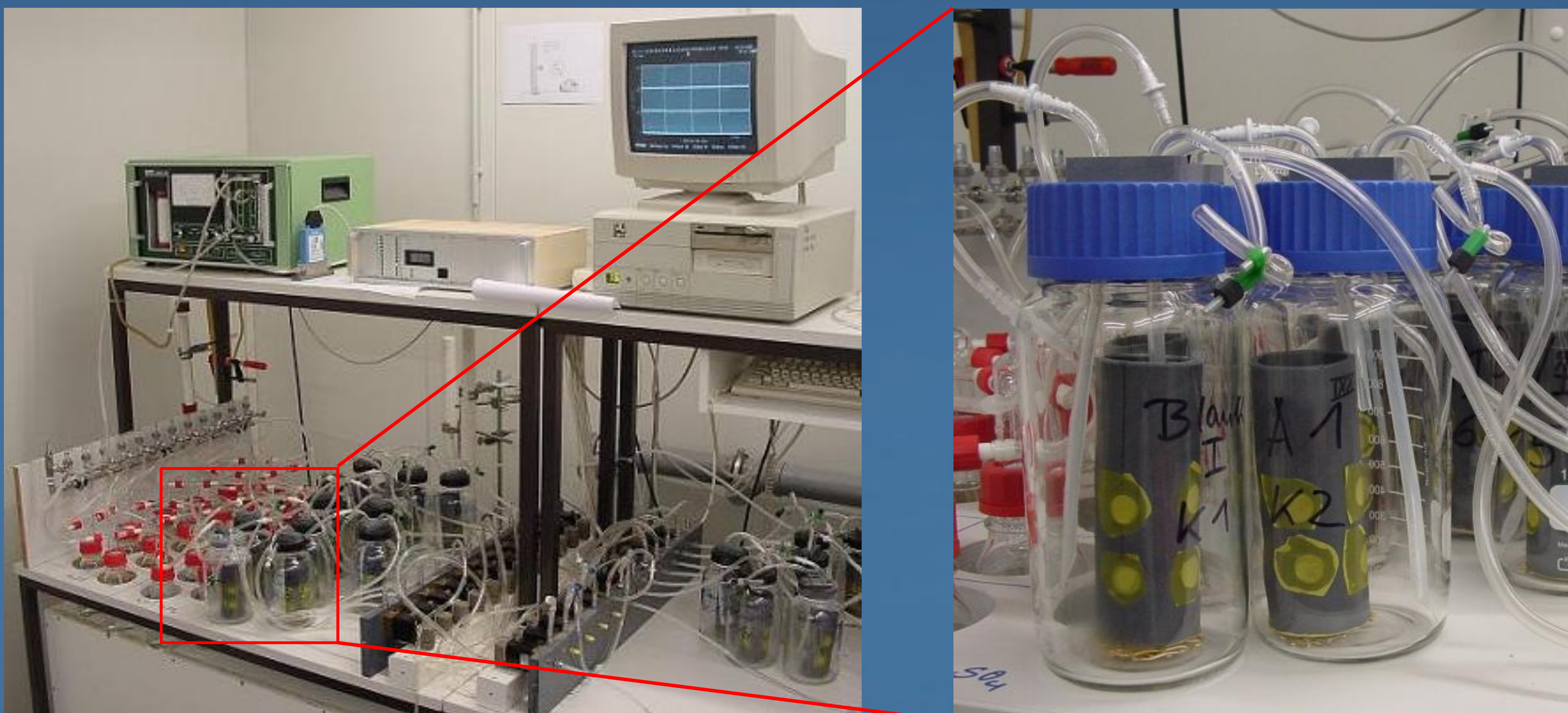
=>Does not separate functional classes

=>No correlation to conceptional pools



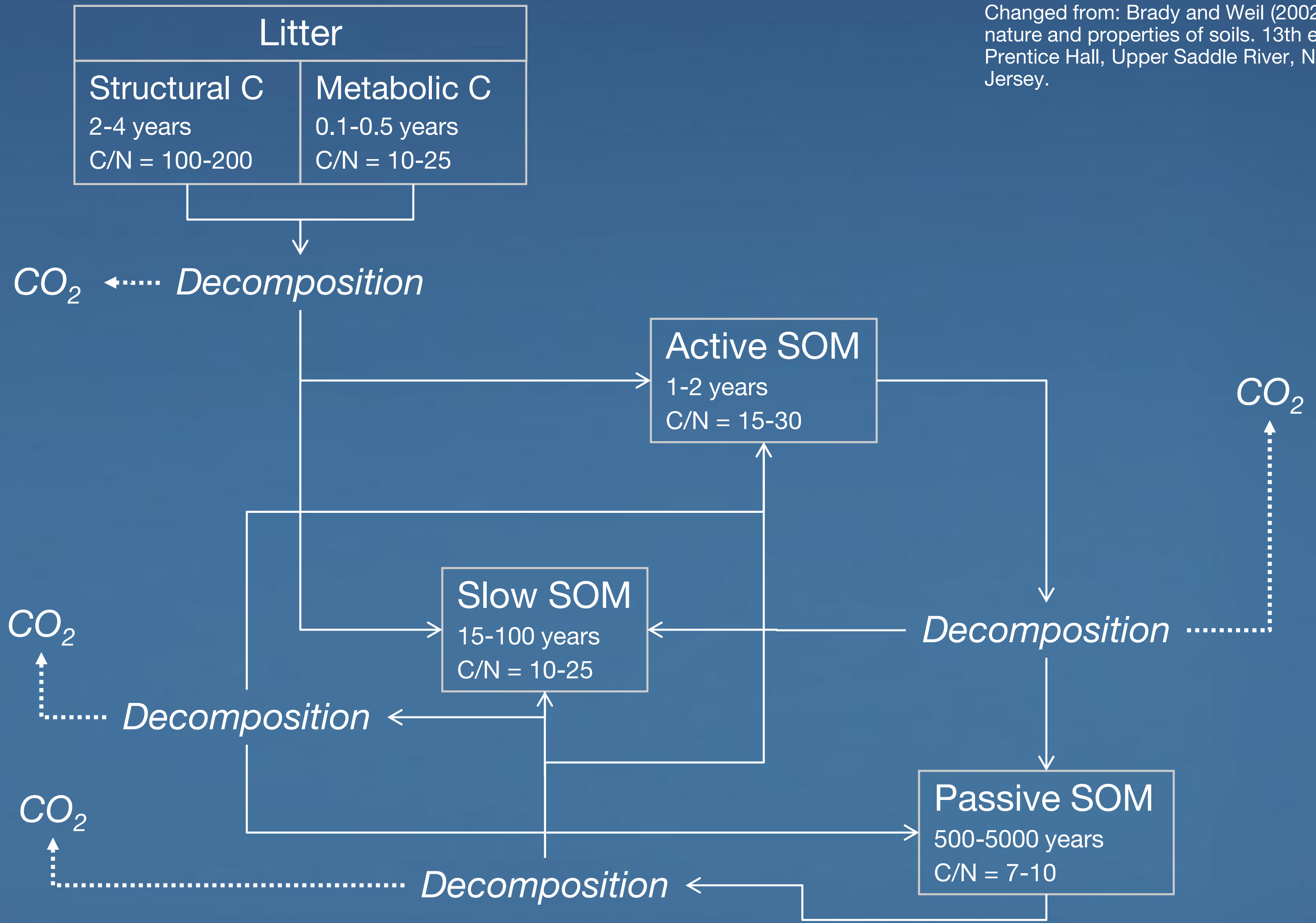
Decomposition of SOM

- Most C is set free during SOM decomposition as CO_2
- Incubation experiments measure the CO_2-production of samples with time (Respiration rate)

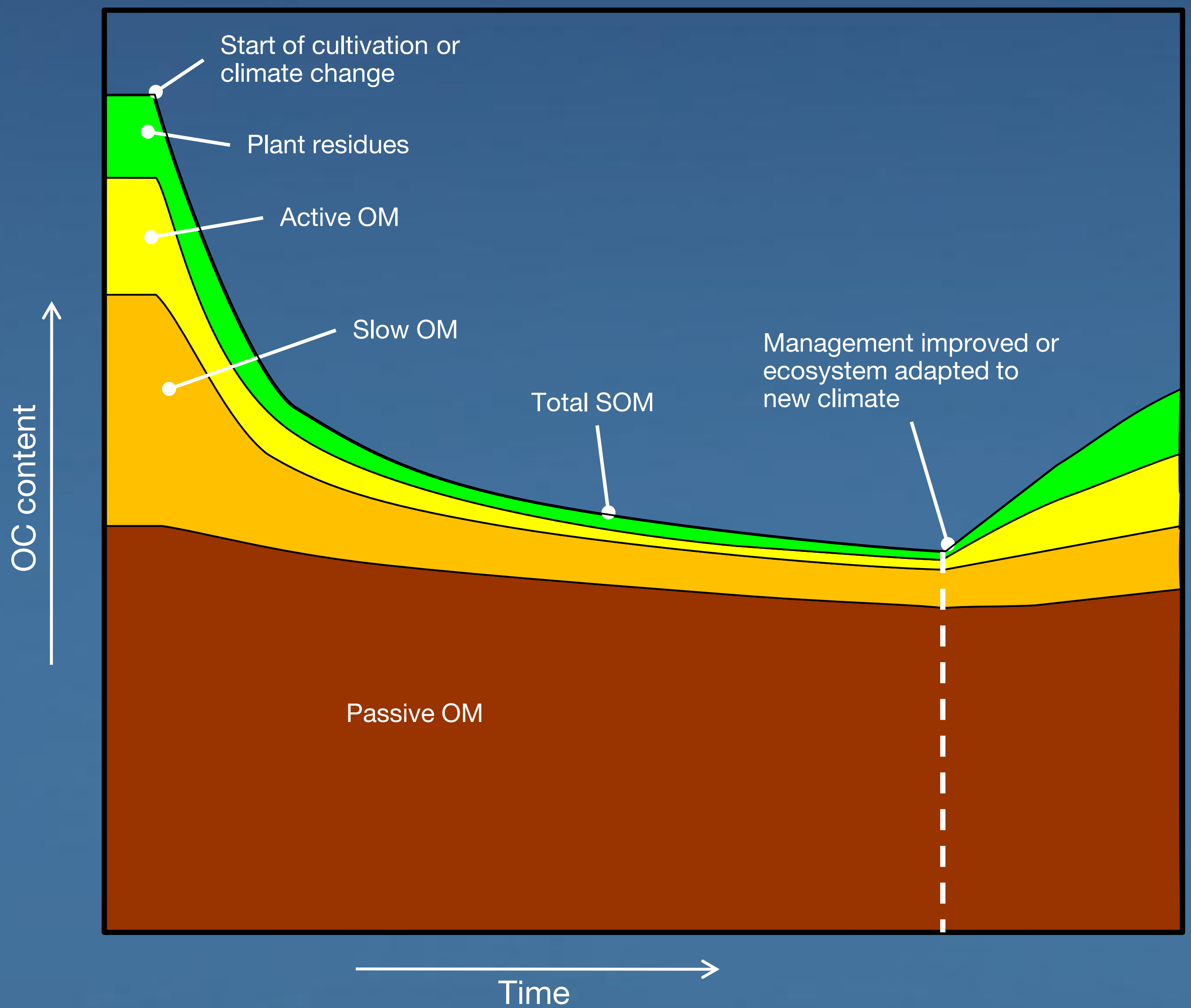


Conceptional pools of SOM (Biological view)

Changed from: Brady and Weil (2002): The nature and properties of soils. 13th edition. Prentice Hall, Upper Saddle River, New Jersey.



Conceptional pools and management



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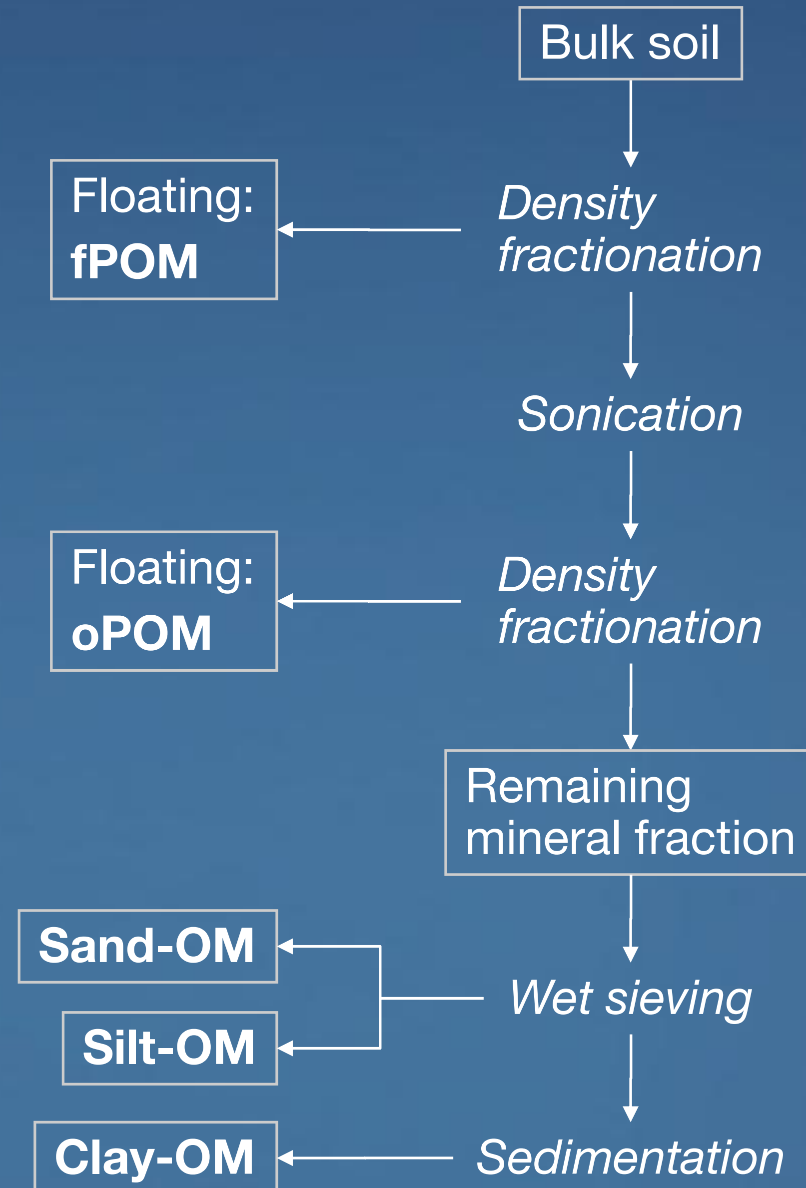
SOM fractions

- Pools: Conceptional (fictional) classes of homogeneous organic matter
  - Homogeneous in physical, chemical and biological aspects
  - But clearly different from each other
- Fractions: Functional (“real”) classes of organic matter
  - Separated in laboratory with physical or chemical methods
  - Classical method: Chemical humin-fractionation
  - Exemplary “new“ method: Physical fractionation

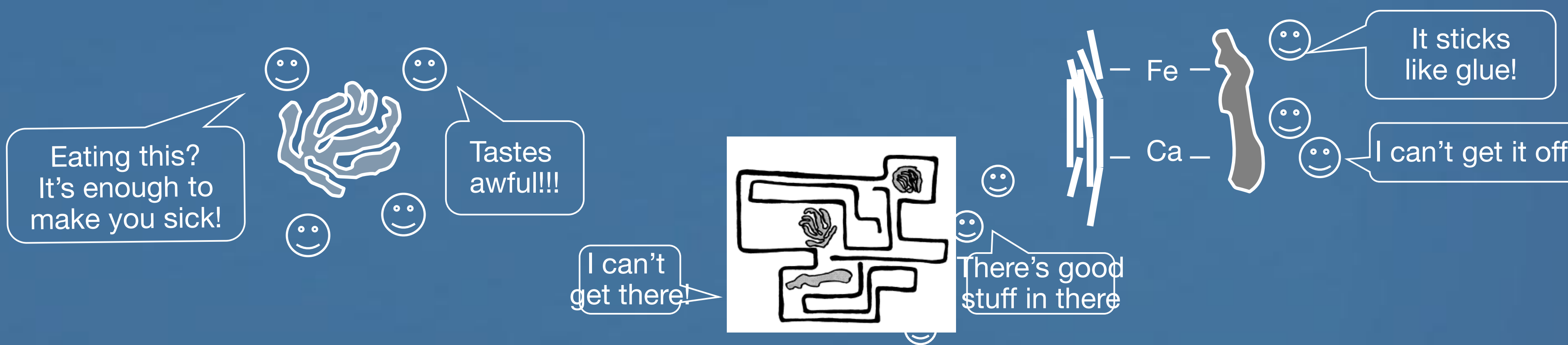
Physical fractionation

- "New" approach to separate functional pools of SOM
  - Combination of density and particle size fractionation
  - Separates many fractions, some might represent conceptional classes
    - fPOM: free particulate OM
    - oPOM: occluded particulate OM
    - Mineral-associated OM
  - Fractions are not changed qualitatively
  - Method can be modified to match the projects requirements (Time, cost, aims)
  - Has to be adapted/adjusted for each soil type



Stabilisation of SOM

- Basically all kinds of OM can be decomposed by destruents
  - OM is a continuum of decomposition
- But there are three (conceptional) stabilisation mechanisms hindering the decomposition of OM completely and/or of selected parts
  - **Recalcitrance** is of mayor importance for fresh OM during the first years of decomposition (Hydrophobic and/or aromatic domains hinder the decomposition of OM) - accumulation of these domains with time while easily decomposable components vanish.
  - OM that is occluded/encapsulated in aggregates (**Spatial inaccesability**) - cannot be reached be destruents or enzymes (also readily available OM can be stabilised by this mechanism).
  - **Adsorption to surfaces** (clay and iron oxides) is more important for highly decomposed/degraded OM. Materials adsorb to fine particle size classes changing their spatial structure making decmposition impossible or hinder it.



Von Lützow et al. (2006): 2006. Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions – a review. European Journal of Soil Science, 57: 426–445.

Herrmann (2003): Predicting nitrogen mineralization from soil organic matter – a chimera? Agraria 429, Doctoral thesis, Uppsala, Sweden.

SOM sequestration through land-use change to mitigate climate change!?

- Bulk soils showed clear differences between different plots. Land-use change or reduced grazing intensity as a tool to face global farming!
  - But in which fraction is this additional carbon stored and how is it stabilised?

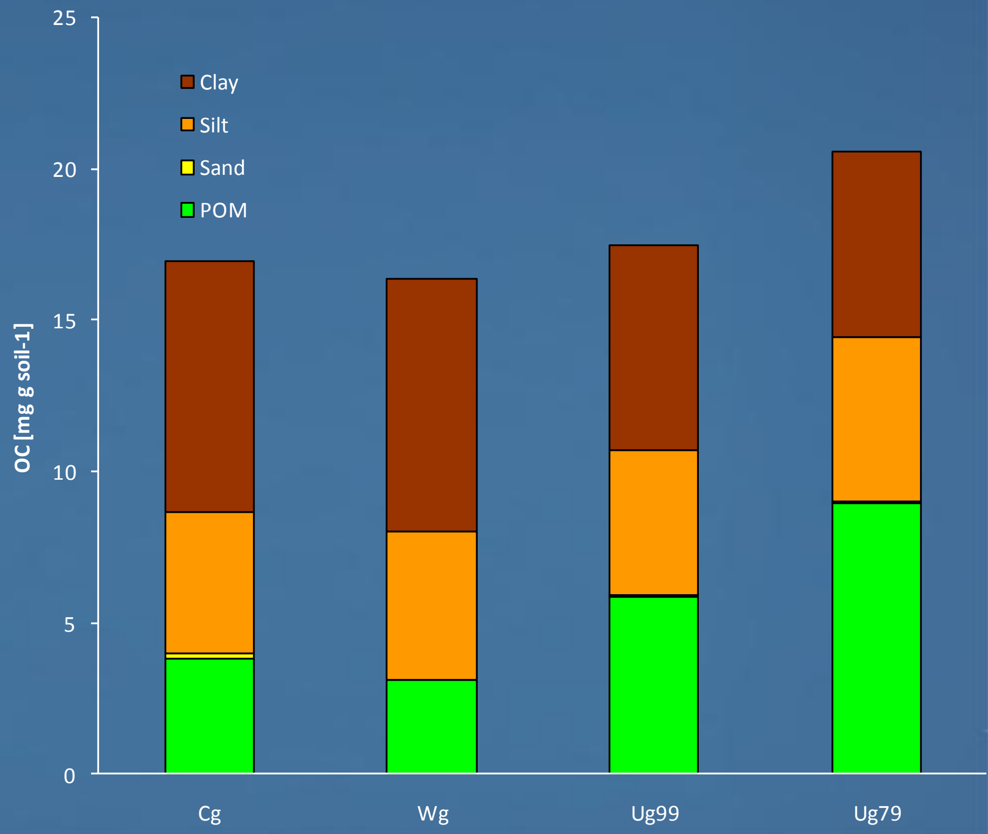
-> Physical fractionation of topsoils

- Combined aggregate size, density and particle size fractionation
- Adjusted sonication energy for optimal aggregate disruption and minimal production of artefacts

=> Predominate storage in POM fractions after 25 years, first hints after 5 years

=> Particle size classes did not change - no stabilised OM in particle size classes!?

- Grazing cessation increased SOM content of the coarse POM fractions of topsoils
- Stabilised only for years
- Processes take time



Steffens et al. (2009): Alteration of soil organic matter pools and aggregation in semi-arid steppe topsoils as driven by organic matter input .- European Journal of Soil Science, 60(2): 198-212.

No SOM sequestration in particle size classes!?

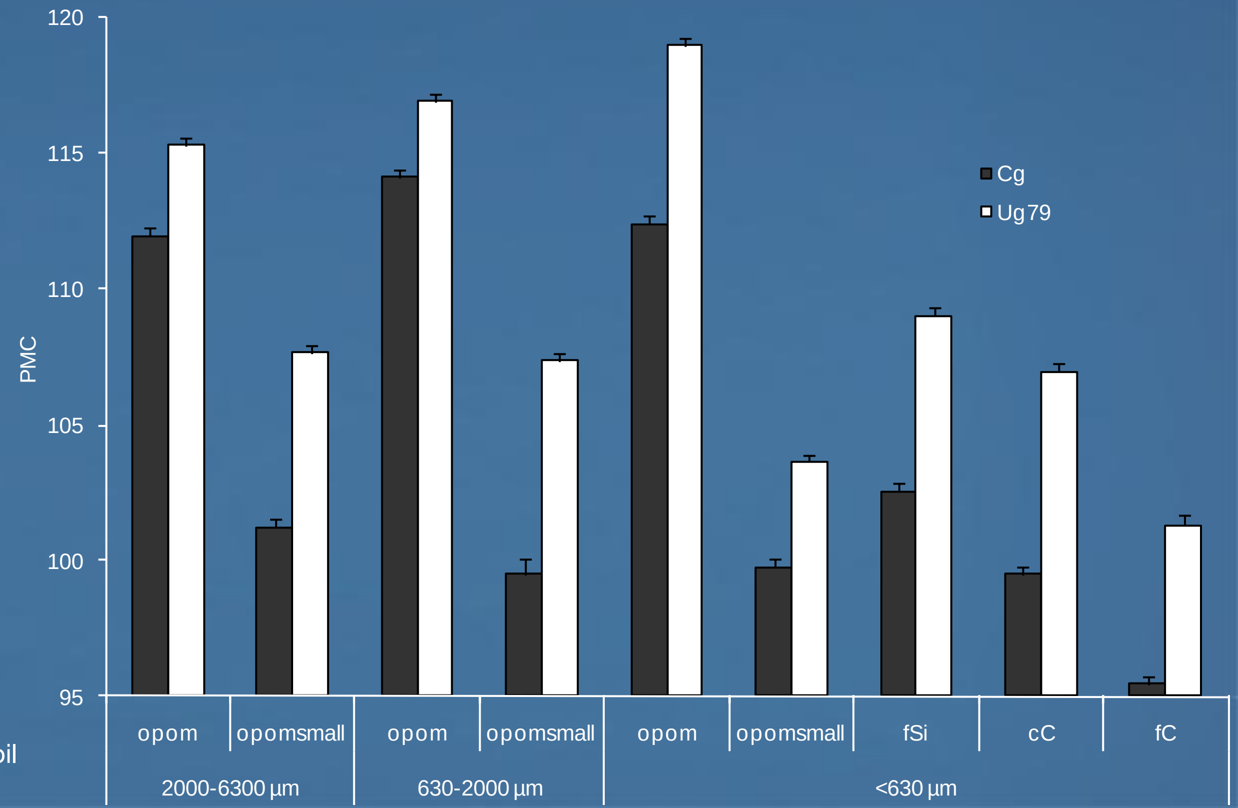
- Particle size classes did not change quantitatively after grazing cessation
- Radiocarbon activities of all fractions were determined (Cg and Ug79)
  - Ug79 showed higher radiocarbon activities (were younger) than Cg across all analysed fractions

-> OM in fine particle size fractions takes part in C cycling, too

=> Input of fresh OM triggered the decomposition of OM in fine particle size classes (Priming effect)

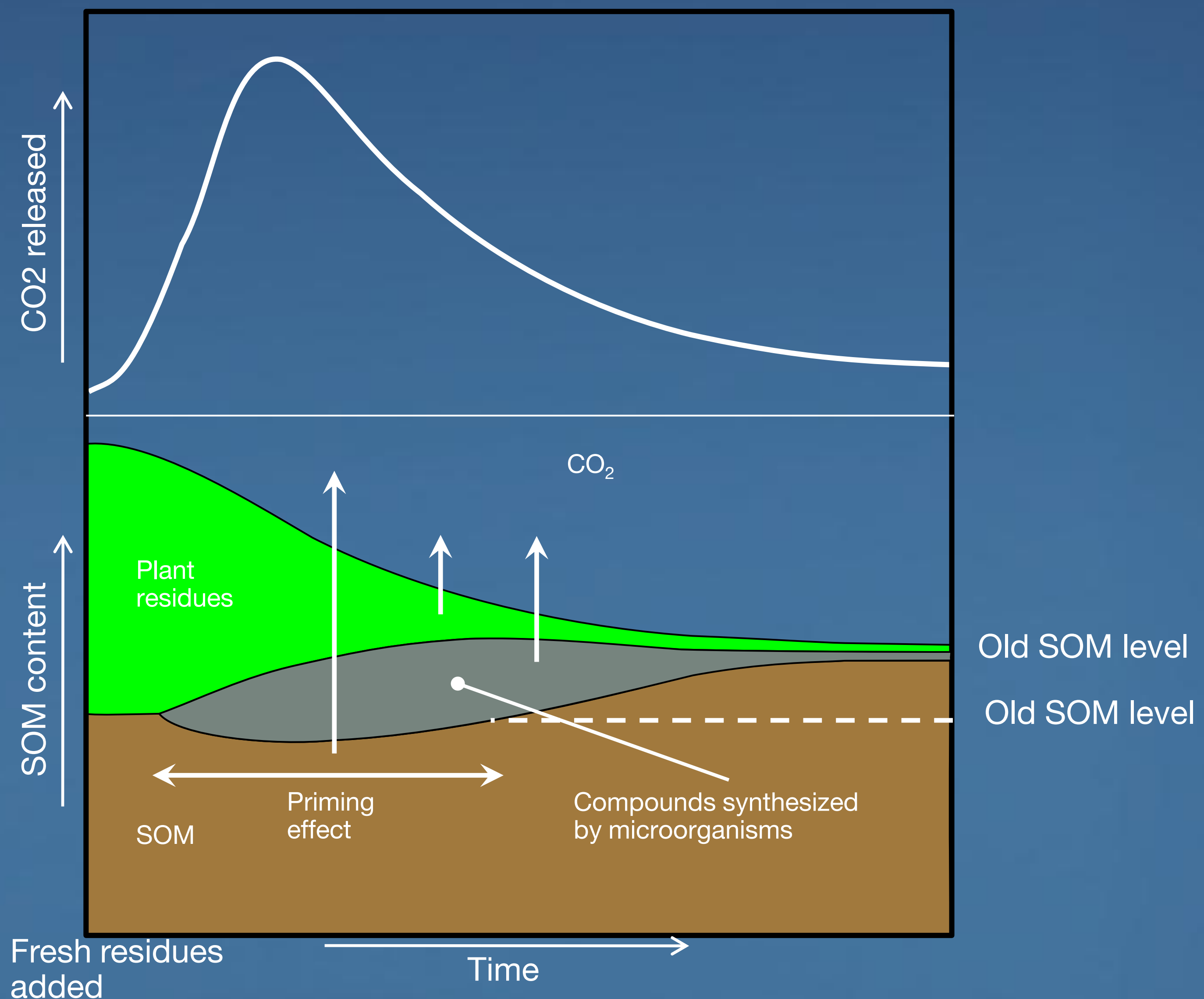
⇒ Fine particle size classes are no passive pool!

Particle size classes have a limited capacity to store SOM (also POM is discussed)



Steffens et al. (2009): Alteration of soil organic matter pools and aggregation in semi-arid steppe topsoils as driven by organic matter input .- European Journal of Soil Science, 60(2): 198-212.

Conceptional model of OM addition



Changed from: Brady and Weil (2002): The nature and properties of soils. 13th edition. Prentice Hall, Upper Saddle River, New Jersey.

Deep soil OM sequestration

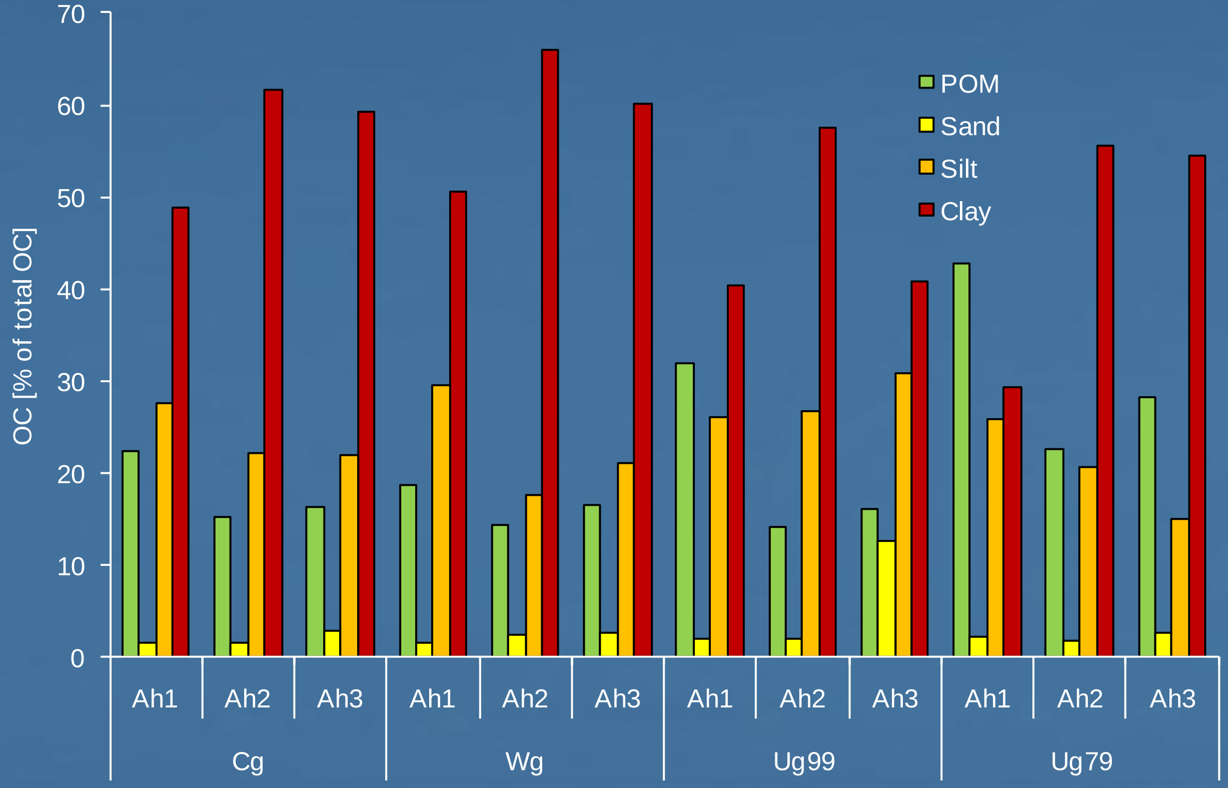
- Most studies analyse topmost layers of soil and neglect deeper layers and horizons
- But processes may change following land-use and climate change
  - Deeper rooting plant species establish and incorporate OM in deeper layers
  - Soil water movement changes to descending direction, transporting dissolved and particulate OM to deeper layers
  - Erosion and deposition processes bury OM-rich upper layers

  -> Processes and stabilisation mechanisms are nearly unknown

SOM sequestration in deeper soil layers?

- Studies on topsoils showed predominate sequestration in readily available POM fractions
- Same fractionation on deeper soil layers
  - Fresh OM reached deeper soil layers after 25 years
  - Additional OM is primarily stored in the readily available POM fraction

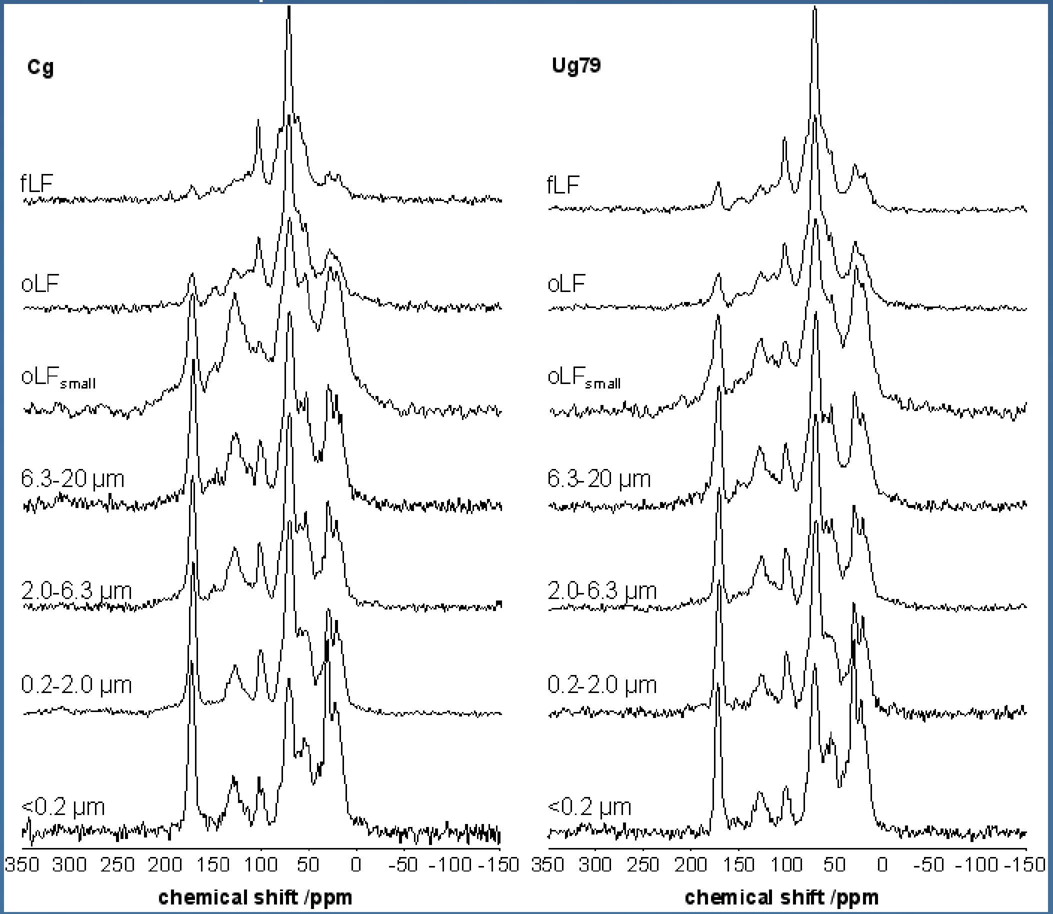
=> Additional OM is not stabilised for longer periods and changing processes may reactivate this pool again



Steffens et al. (Accepted): Distribution of soil organic matter between fractions and aggregate size classes in grazed semiarid steppe soil profiles.- Plant and soil.

Quality of SOM fractions

- Many instruments and techniques to analyse the quality of SOM fractions
- MAGIM samples analysed with solid-state ^{13}C NMR spectroscopy
    - Elucidates chemical bonds of C atoms in the sample



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Conclusions

SOM is...

... of great importance for grassland systems

... affected by land-use and climate change

... variable on different scales

... affected by many factors, depending also on the observed scale

... sequestered in grassland systems and stabilised with different mechanisms

... measurable with easy methods

... offers many opportunities for future studies

Thanks are due to…

- GrassNet and Marc Giese - invitation
- DFG - financial support during my PhD-thesis
- MAGIM research group - great collaboration and many friends
- Institute of soil science at the TU München - Technical assistance and scientific guidance
- You - attention