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University of Applied Sciences

# Soil and soil fertility

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# Agenda

## Soil and soil fertility

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2. *Soil formation*
3. *Soil physics*
4. *Water in the soil*
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   3. *Soil pH*
   4. *C/N ratio*
6. *Soil organic matter (SOM)*
   1. *Humification*
   2. *Dynamic Stability of Soil Carbon*

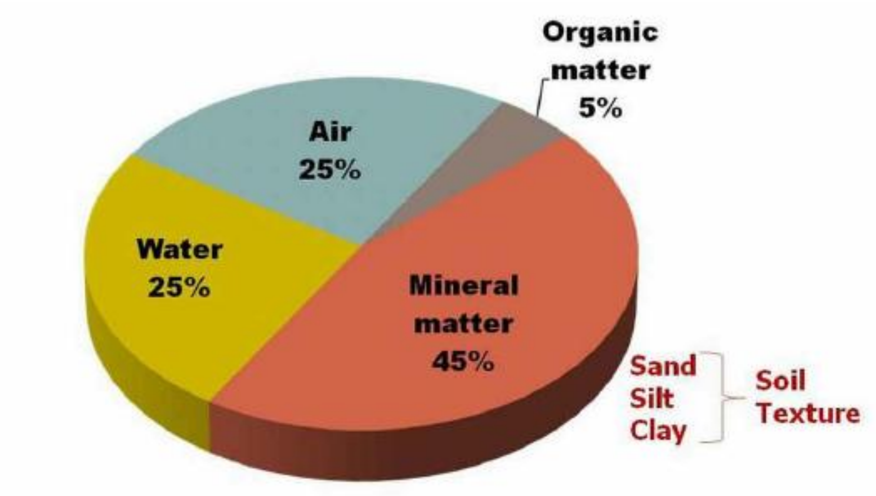
# Introduction

Soil is one of the most important factors and resources in agriculture. Crops are grown on it. Plants draw nutrients and water from the soil. To gain a better understanding of why soil is so important, we will examine topics such as soil composition, soil types, soil fertility and their impact on plant growth.

# Soil components

Soil consists of several components. These are:

- Mineral particles → determine the texture (sandy, silty, clayey)
- Soil organic matter → organic materials that are, or have been, part of living organisms (e.g. earthworms, bacteria, fungi → break down organic matter)
- Soil water → a medium for transporting nutrients.
- Soil air → roots need to breathe



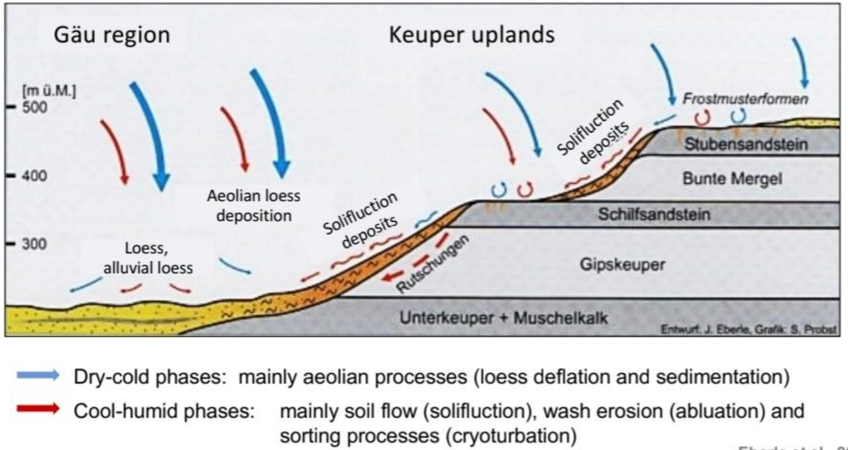

https://www.researchgate.net/figure/Typical-Components-of-Soil_fig1_239553122

# Soil formation

But how is soil actually formed?

Soil formation, also known as pedogenesis, is a process that takes place over a long period of time. Five factors influence this process: climate, organic matter, topography, parent material and time. As these factors vary around the world, soil types differ from place to place.

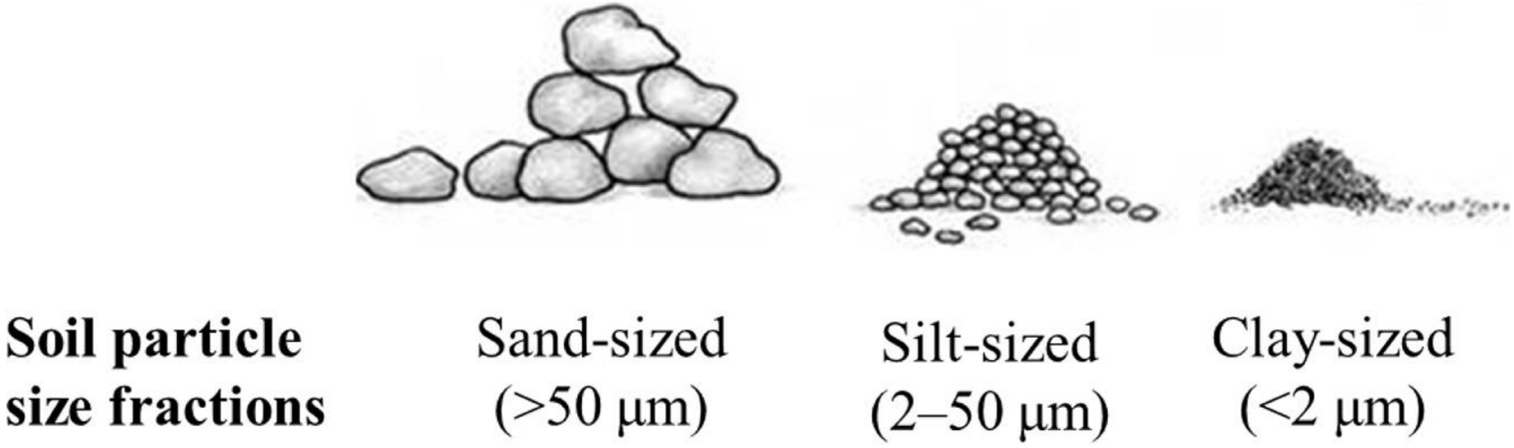
Example: Soil formation in southern Germany




Eberle et al., 2010

# Soil physics

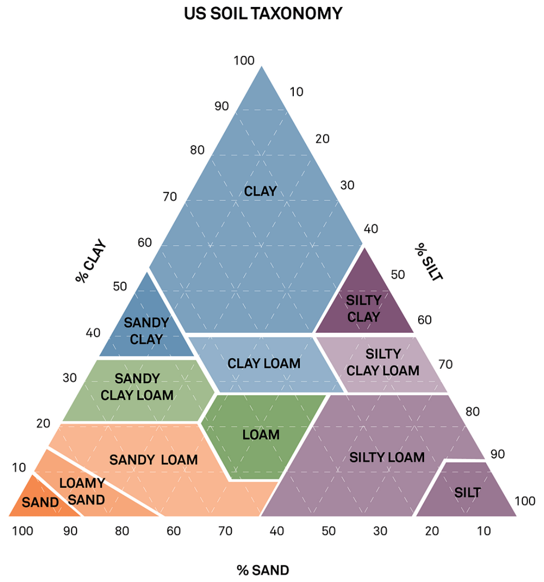
Soil can be divided into particle size fractions.




https://www.sciencedirect.com/science/article/abs/pii/S004896971833403X

# Soil physics

The different particle size fractions have specific properties. Soil consisting mainly of the primary soil type sand, for example, is easy to work but has poor water retention. In contrast, a clayey, heavy soil is difficult to work and retains water very well. The depth of root penetration is also strongly influenced by the soil. Root penetration depth depends on soil type, bulk density, depth of development, water flow and coarse soil content.




https://metergroup.com/app/uploads/2023/05/us-soil-taxonomy.png

# Soil physics

Soil structure refers to the arrangement of solid soil particles. In agriculture, the rule is: the more compacted the soil, the less favourable it is.

Soil structure is formed through various processes.

1. Coagulation: mineral and COM particles clump together to form coagulates (influenced by liming and organic fertilisation)
2. Biological consolidation: by soil organisms (promote soil life)
3. Shrinkage and swelling: due to fluctuating moisture content in the soil
4. Frost and thaw: mechanical energy breaks down aggregates

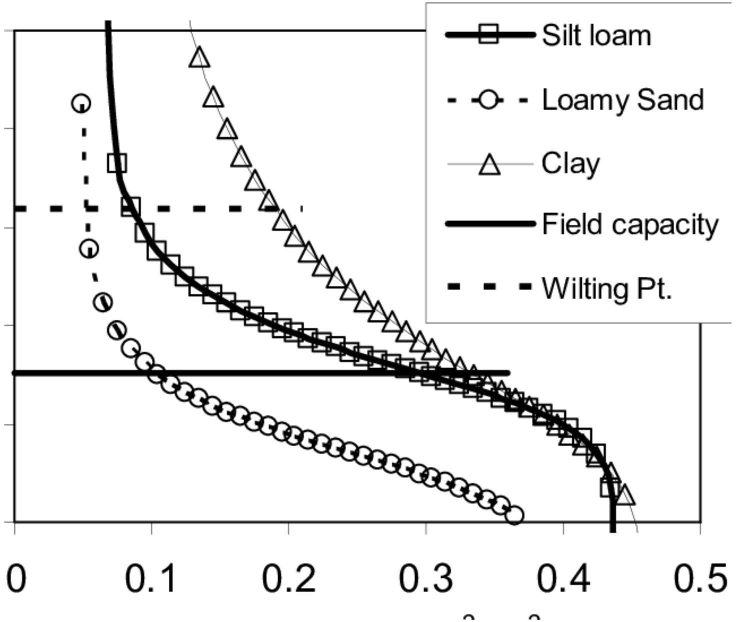
Loose soil is desirable in agriculture, as plants can root through it easily and water is absorbed more effectively. Furthermore, this means that more oxygen is available to the plants.

The soil can become compacted due to the use of machinery that is too heavy or driving on wet ground.

# Water in the soil

Water is essential for plant growth. It is therefore crucial to understand how water moves through the soil and how it is retained there.

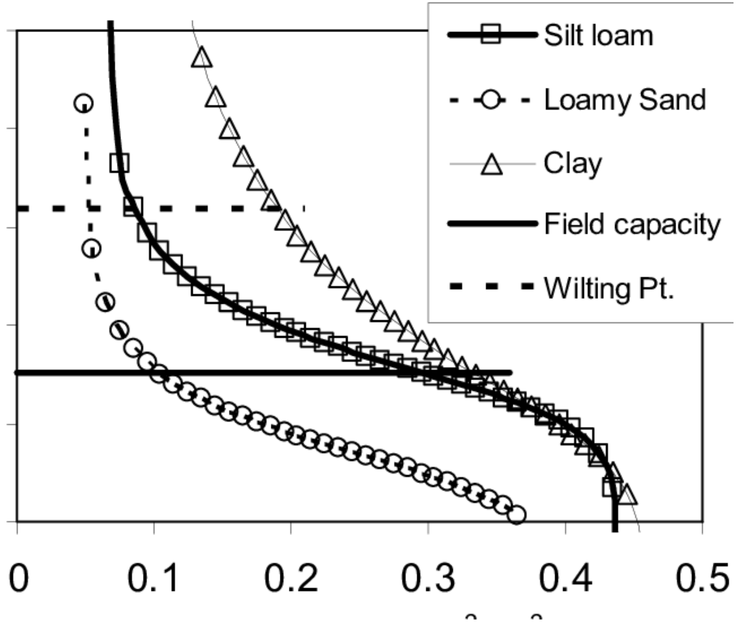
Water retention depends heavily on the soil type. In sandy soils, for example, there are many large pores which cannot hold water as firmly. The smaller the pores, the greater the retention capacity. The ability to 'hold' water is referred to as matrix potential (= water retention capacity).




https://www.researchgate.net/figure/The-soil-water-content-vs-soil-water-matric-potential-relationship-for-three-soil_fig6_228647549

# Water in the soil

This diagram also shows a few other relevant key terms: permanent wilting point (= any water held in a state more solid than the permanent wilting point is not available to plants), field capacity (= the total amount of water the soil can hold), air capacity (= these pores are too large to hold water).



# Soil chemistry - nutrients

The soil contains mineral nutrients, some of which are also stored there. How well they can be retained in the soil depends on the nutrient concentration, the pH and the cation exchange capacity (CEC).

Nutrients are present in the soil as ions in the soil solution.

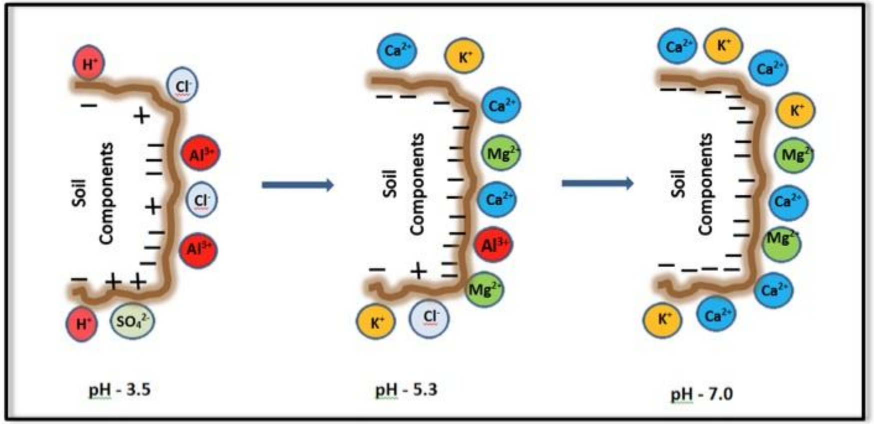
Important nutrients:

- N as $NO_3^-$, $NH_4^+$
- S as $SO_2$, $SO_4^{2-}$
- P as $PO_4^{3-}$
- K as $K^+$
- Ca as $Ca^{2+}$
- Mg as $Mg^{2+}$

# Soil chemistry – Cation exchange capacity

The positively charged ions (cations) can bind to the negative charges of the clay minerals; this is known as cation exchange capacity (CEC).

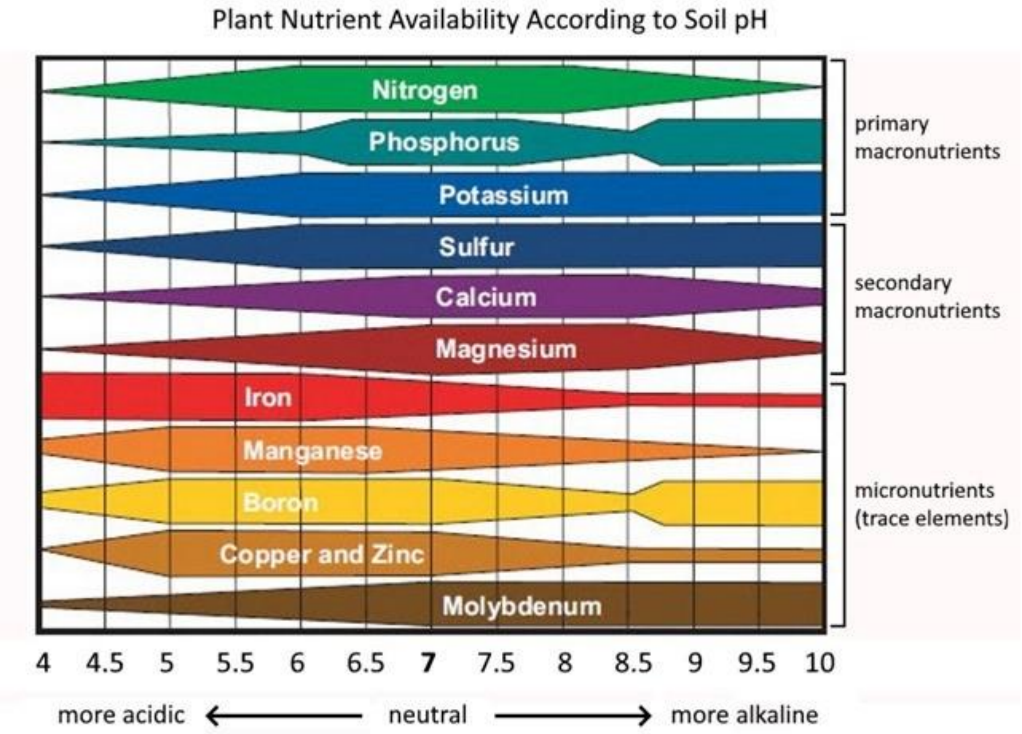
A distinction is made between potential and effective cation exchange capacity. Effective CEC is the actual CEC at the current pH value. In an acidic soil solution, H3O+ ions (oxonium ions) predominate. These can also occupy the cation exchange capacity and thus block mineral nutrients. In soils with a basic pH, on the other hand, there are more 'vacancies' in the CEC. One measure to increase the pH is to apply lime.




https://fieldreport.caes.uga.edu/publications/C1040/cation-exchange-capacity-and-base-saturation/

# Soil chemistry – soil pH

The pH level has a significant impact on nutrient availability.




https://soiltesting.cahnr.uconn.edu/soil-ph-and-management-suggestions/

# Soil chemistry C/N ratio

- Describes the ratio of carbon to nitrogen in organic material and is a measure of its degradability
- Low C/N ratio (< 20:1, e.g. slurry, clover-grass): rapid microbial degradation, rapid N mineralisation → nutrient release
- Wide C/N ratio (> 30:1, e.g. straw, sawdust): slow decomposition, microorganisms immobilise N → temporary N fixation
- The C/N ratio of the soil itself is in equilibrium at around 10–12:1 – a sign of stable humus quality

# Soil organic matter (SOM)

- Soil organic matter (SOM) = the totality of organic matter in the soil – living, dying and dead
- Distinction: nutrient SOM (labile pool, rapidly degradable, nutrient-supplying) vs. permanent SOM (stable pool, humic substances, long-term in the soil)
- SOM is not a static material, but the result of a dynamic equilibrium between the input, transformation and decomposition of organic matter
- Key players: Soil organisms (bacteria, fungi, earthworms) drive transformation and stabilisation

# SOM - Humification

- Humification = the biochemical process of converting fresh organic matter into stable humic substances

SOM quality vs. SOM quantity

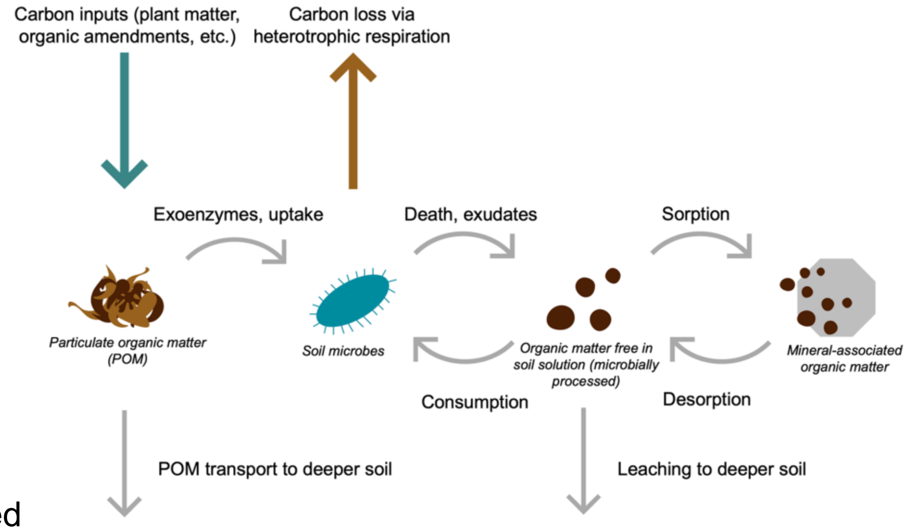
- Quantity = measurable content of organic carbon ($C_{org}$) in the soil – important, but not meaningful on its own
- Quality describes functional effectiveness: C/N ratio, degree of stabilisation, microbial activity, aggregate stability
- Soil can have a high $C_{org}$ content yet still be biologically inactive or structurally unstable
- Crucial for soil fertility: the interaction between these two factors

Farming practices have a major influence on $C_{org}$ content: crop rotation, tillage (depth, intensity), organic fertilisation and fallow periods.

# SOM - Dynamic Stability of Soil Carbon

New understanding of SOM:
Most soil organic matter is microbial in origin — built from dead microbe fragments (necromass), up to ~80%. So microbial activity builds long-term carbon — it isn't just a threat to it. Carbon binds to minerals (MAOM) and aggregates, but these bonds are reversible, not permanent.

Dynamic stability:
Carbon lasts not because it's indestructible, but because microbes are physically and biologically constrained from reaching it (<1% of soil surfaces are colonized). Carbon constantly cycles: plant input → microbes → necromass → sorbed to minerals → released → consumed again → moved deeper. Old carbon accumulates especially in deep soil (>30 cm), where microbes are scarce.




https://www.frontiersin.org/journals/environmental-science/articles/10.3389/fenvs.2020.514701/full

# Thank you very much for your interest!

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