C and N cycling in agricultural ecosystems

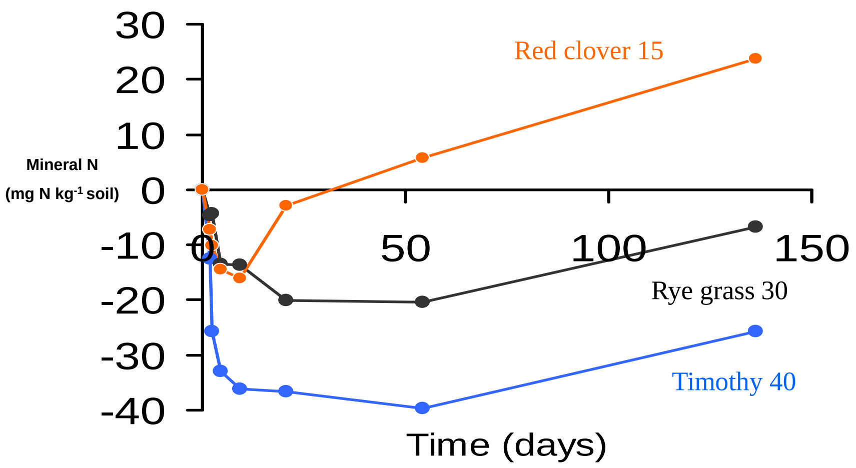
Thomas Kätterer
Dept. Soil and Environment

Outline

- Short-term and long-term effects of organic amendments and N fertilization on soil C, N turnover – plant nutrition perspective
- Agricultural soils and their role in the global C and N cycles
- Land use and agricultural management affecting soil C balances
- SOM affecting soil properties
- Principles of applied C, N modeling

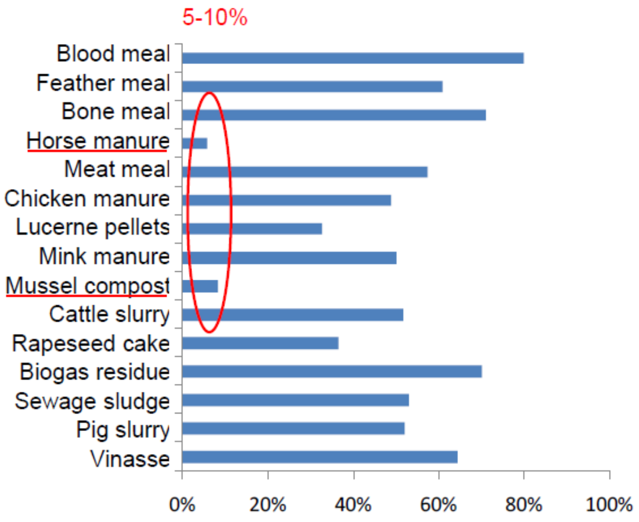
Short-term effects – nutrient delivery :

C/N ratio is often used as indicator for predicting N mineralization



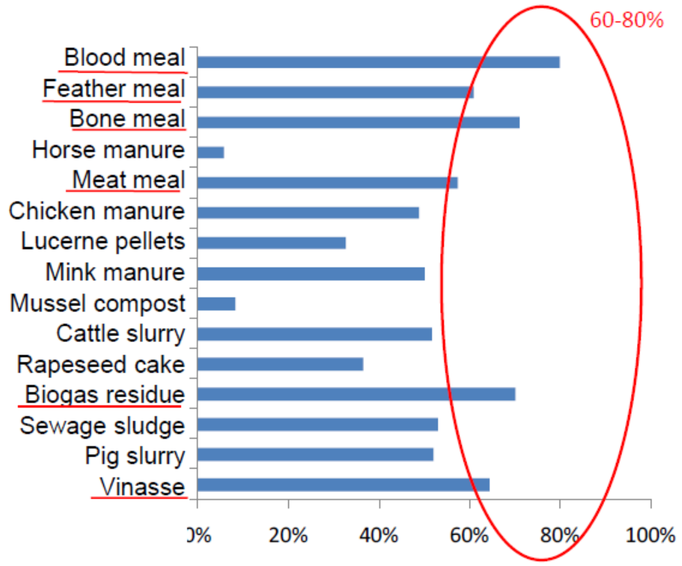
Gunnarssson and Marstorp (2002)

Mineral fertiliser equivalent



Delin et al., 2011

Mineral fertiliser equivalent



Delin et al., 2011

Impact of organic amendments in a longer time perspecitve:

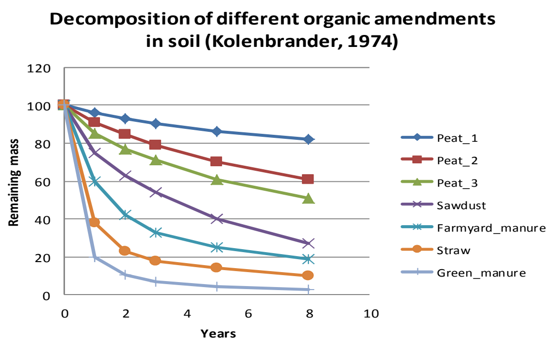
Definitions of 'humification coefficient'

The proportion of mass (SOM or C) added to soil that is

i) left in soil xx years after application, or

ii) entering a slow pool in a model

Example:



Problems: Definitions are not consistent between studies due to differences in time scale, ash corrections, assumed C% etc.

Long-term effects in Swedish long-term experiments

The same amount of carbon is added every second year in different amendments +/- mineral N fertilizers.

Ultuna 60°N, started 1956, clay loam, *Eutric Cambisol* ,1.5% C initially

15 treatments in 4 randomized blocks, plot size 4 m^2 managed by hand

Mainly spring cereals, maize since 2000

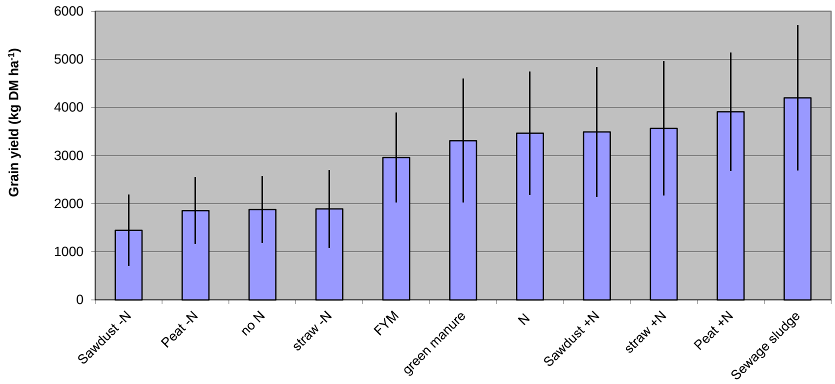
Lanna 58°N, started 1996, clay, *Eutric Cambisol*, 2% C initially

9 treatments, 4 randomized blocks, plot size about 100 m^2

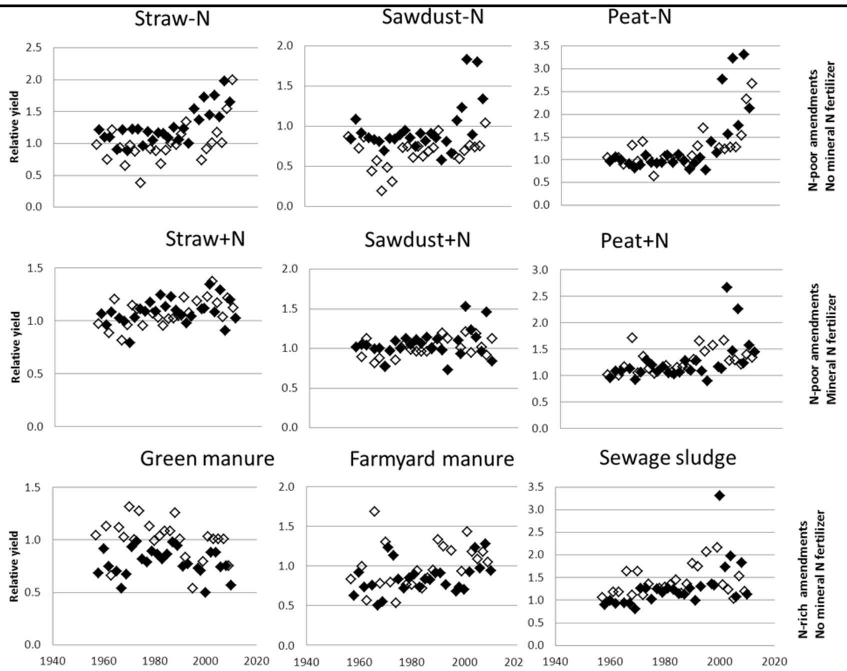
Spring cereals

The Ultuna soil organic matter experiment

Ultuna SOM experiment: Average yields in spring cereals



How do bi-annual additions of organic amendments affect crop yields in a short- and long-term perspective?

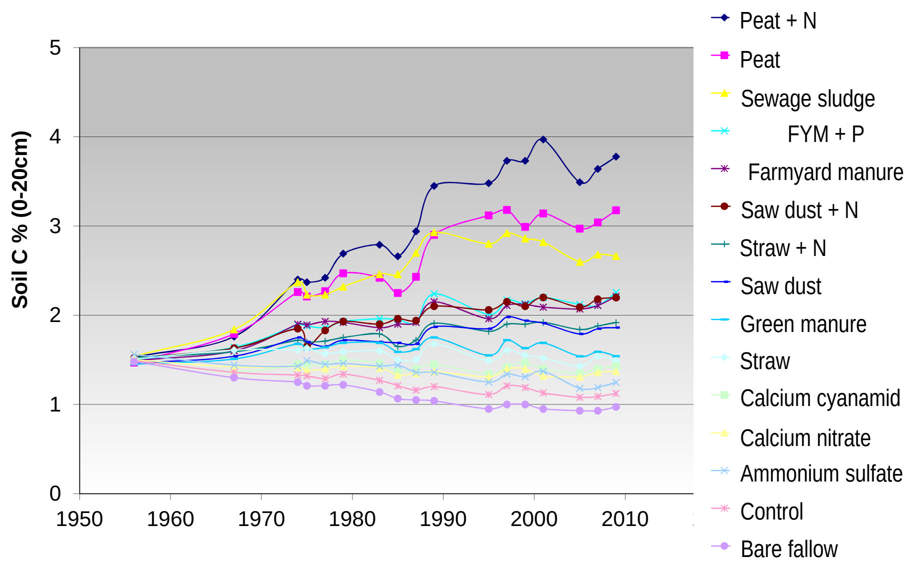


Open symbols: First year after application of organic amendments
Closed symbols: Second year after application of organic amendments

Effects of organic amendments on yields

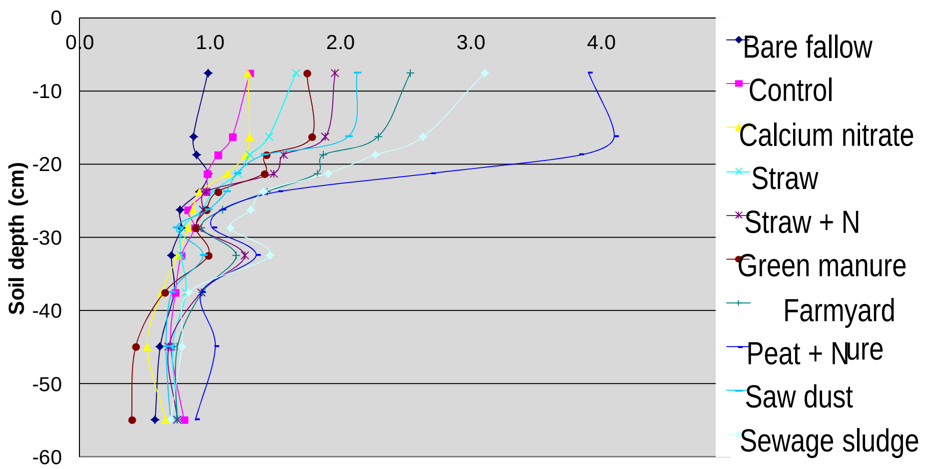
- **Short-term effects** are determined by their nutrient content and decomposition rate
- **Long-term effects** are more determined by their effect on SOM
  – directly
  – indirectly by stimulating plant growth wich results in higher C input to soil.

Changes in topsoil C over time in the Ultuna frame trial



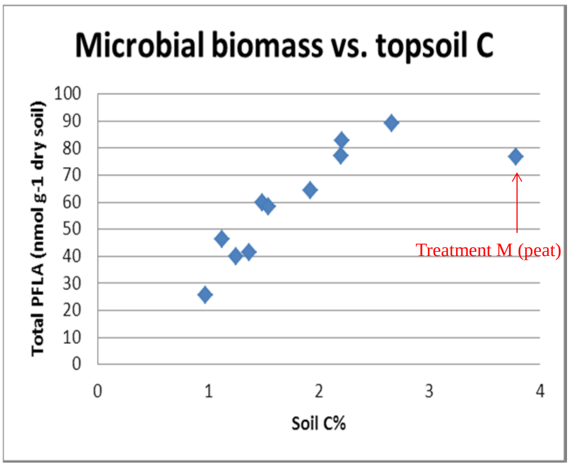
Kätterer et al. (2011) Agriculture, Ecosystem and Environment 141, 184-192

Soil C concentrations in selected treatments of the Ultuna frame trial (2010)



Unpublished data

SOM changes are affecting many soil processes and properties

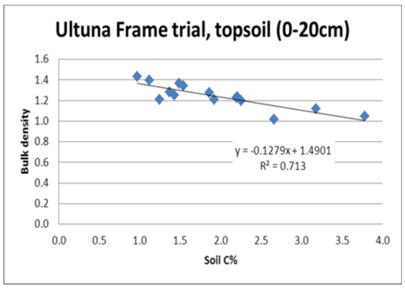


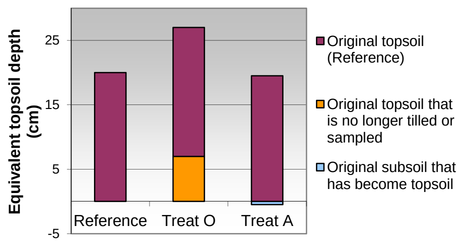
Soil biomass increases almost 3 times when doubling soil C%

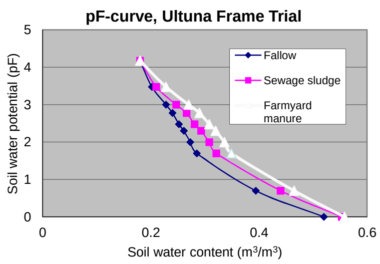
Thus, accessability of SOM for microbes increases with increasing soil C.

Börjesson et al., in press

SOM changes are accompanied by changes in soil physical properties



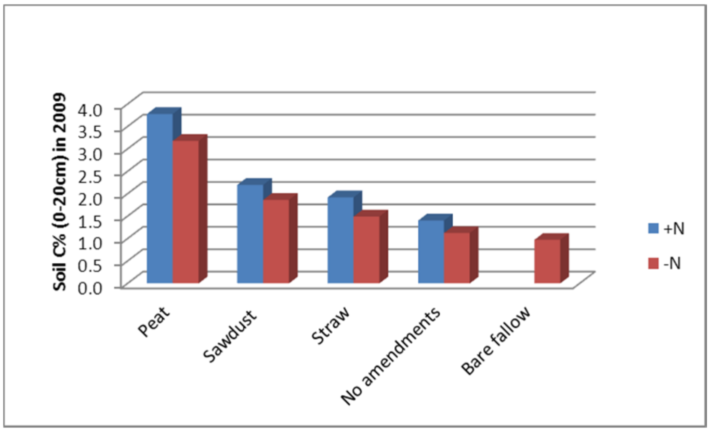




Plot elevation differs by up to 7 cm between treatments

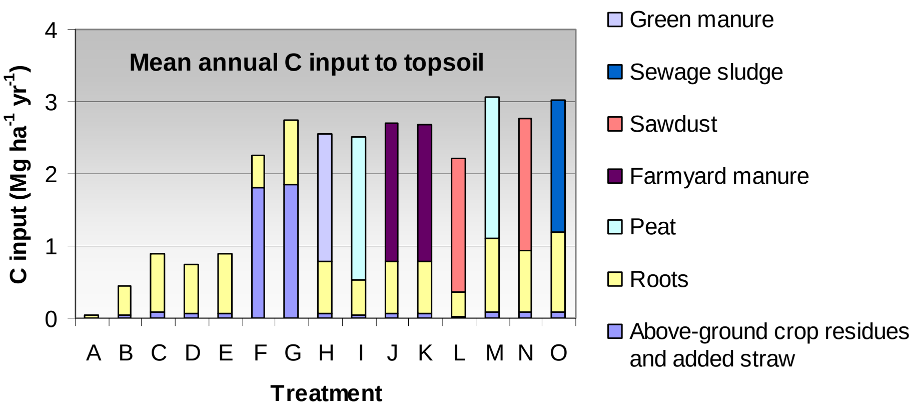
Kirchmann & Gerzabek, 1999
Kätterer et al., 2011

The effect of amendments and roots on soil C is obvious when comparing N fertilized and unfertilized treatments

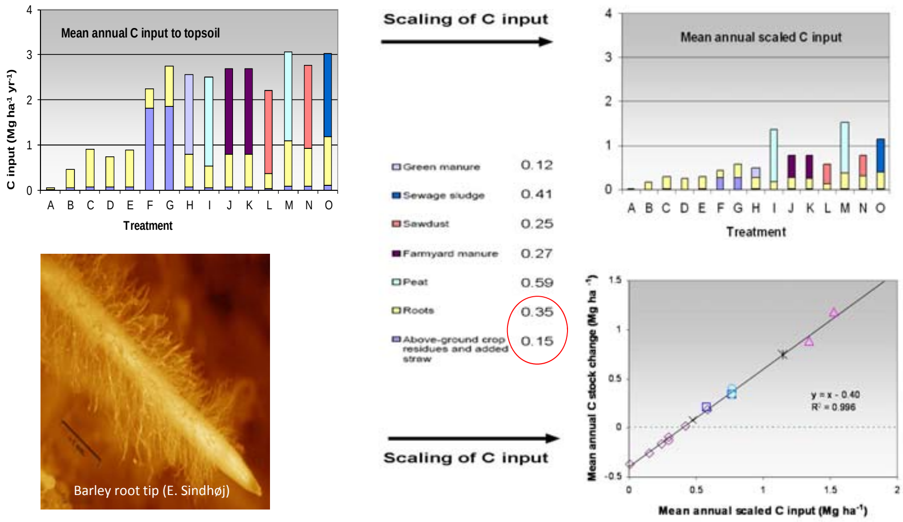


N fertilization results in higher root production and higher soil C stocks

C inputs from organic amendments and crops



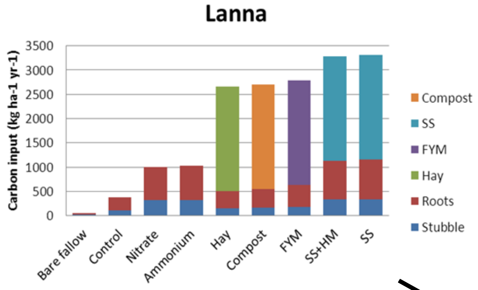
Bolinder et al., 2007; Kätterer et al., 2011

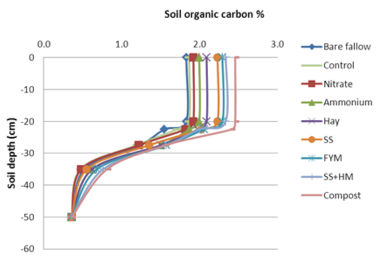


Strong evidence that roots contribute relatively more (about 2.3 times more) to ’stabilized’ soil carbon than above-ground crop residues

Kätterer et al., 2011

Results from Lanna exp. (1996-2009) are confirming the preferential stabilization of root C

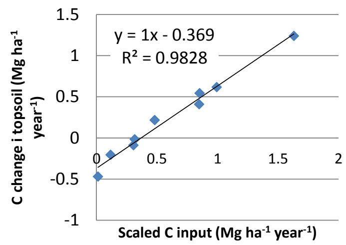




scaling

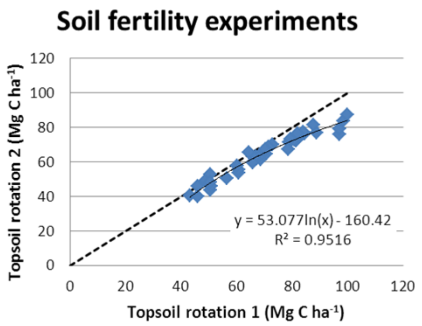
Humification coefficients

Stubble	0.12
Roots	0.31
Hay	0.12
FYM	0.22
SS	0.16
Compost	0.47



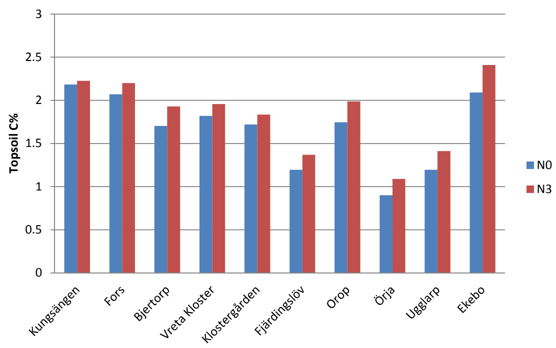
Effect of crop rotation in the fertility experiments (4 N-levels) in Southern Sweden since 1957

Rotation 1	Rotation 2
Spring barely	Spring barley
Ley	**Oilseed**
Winter wheat	Winter wheat
Sugar beet	Sugar beet



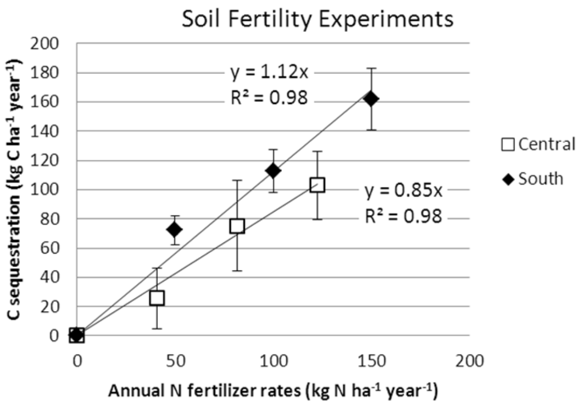
- **Higher yields in rotation 1 (6% in in sugar beets)**
- **Higher C stocks in rotation 1**
- **Effects of crop rotation are in average 130 kg C ha^{-1} year^{-1} and are stronger in more C-rich soils**

N fertilization has about the same impact on soil C as crop rotation in the soil fertility experiments



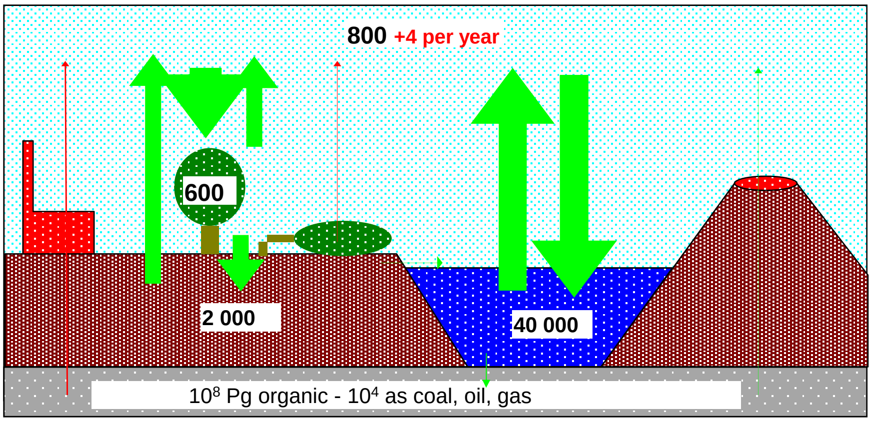
Differences between high N och no N treatments correspond to 30 - 200 kg C per year (average over all PK-level, rotation 2)

Impact of N fertilization on soil C sequestration



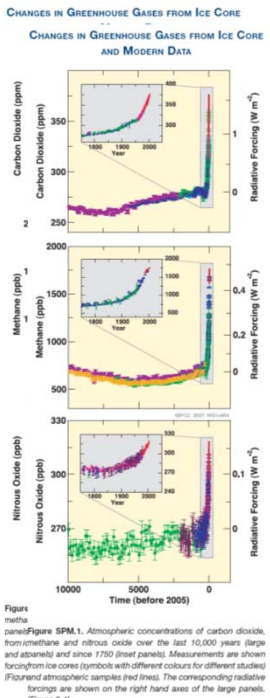
About 1 kg C is sequestered for each kg N applied.
The response seems to be independent on fertilizer rate

Soils play a central role in the global C cycle (Pg C)



Thomas Kätterer, 1998

Atmospheric concentrations of greenhouse gases



CO_2

CH_4 × 25

N_2O X 298

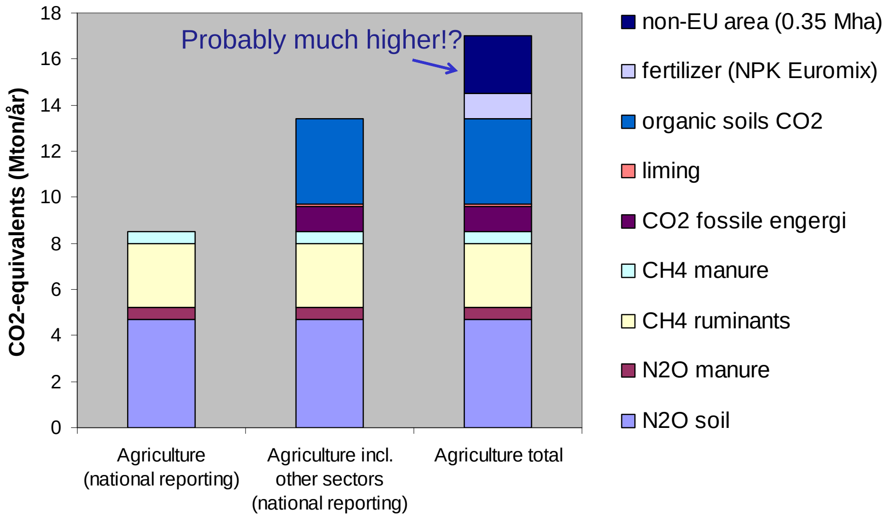
<u>Contribution of Swedish agriculture to national emissions:</u>

50% of CH4 (ruminants)

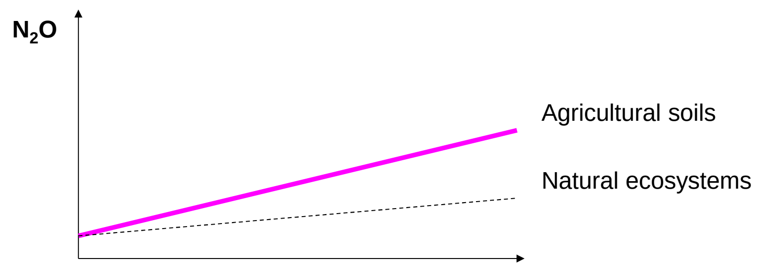
70% of N2O (soil & manure)

7% of CO_2 (organic soils, energy use, liming)

Greenhouse gas footprints of Swedish food consumption



N_2O from soils - controling factors



Soil water content, SOM, clay, temperature,

N intensity (fertilizer, legumes)

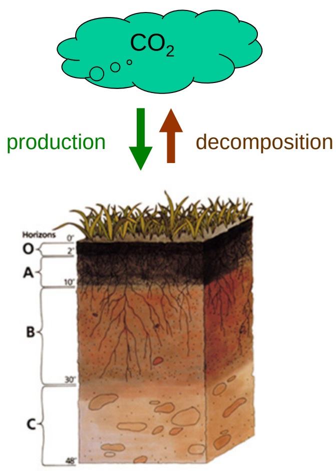
Crop (grass < cereals < legumes)

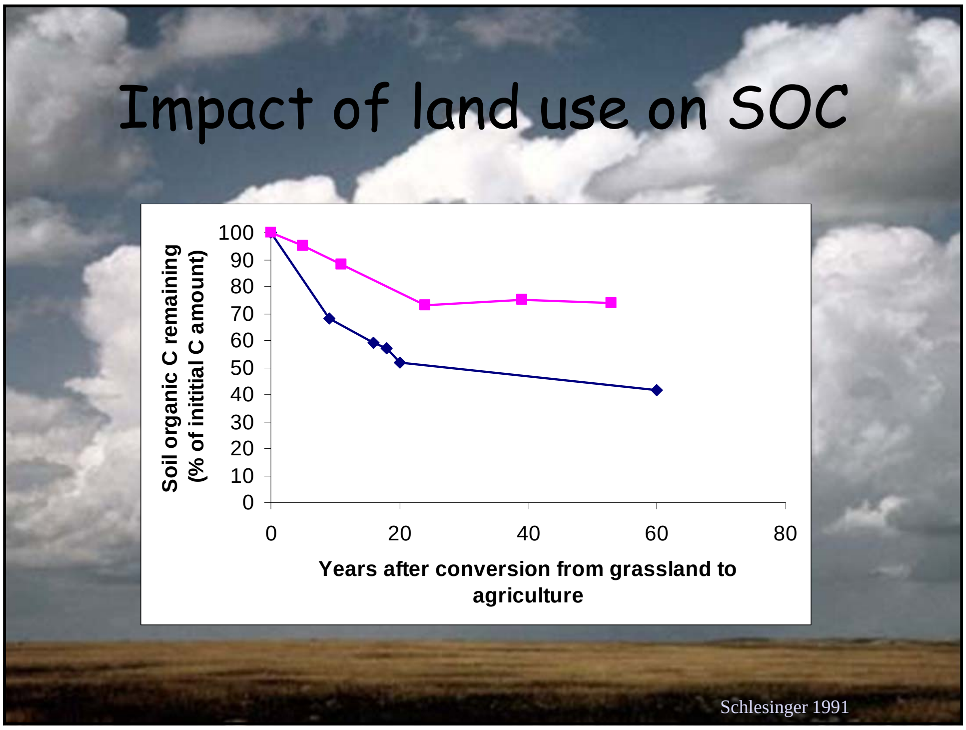
Soil C balances are governed by production and decomposition

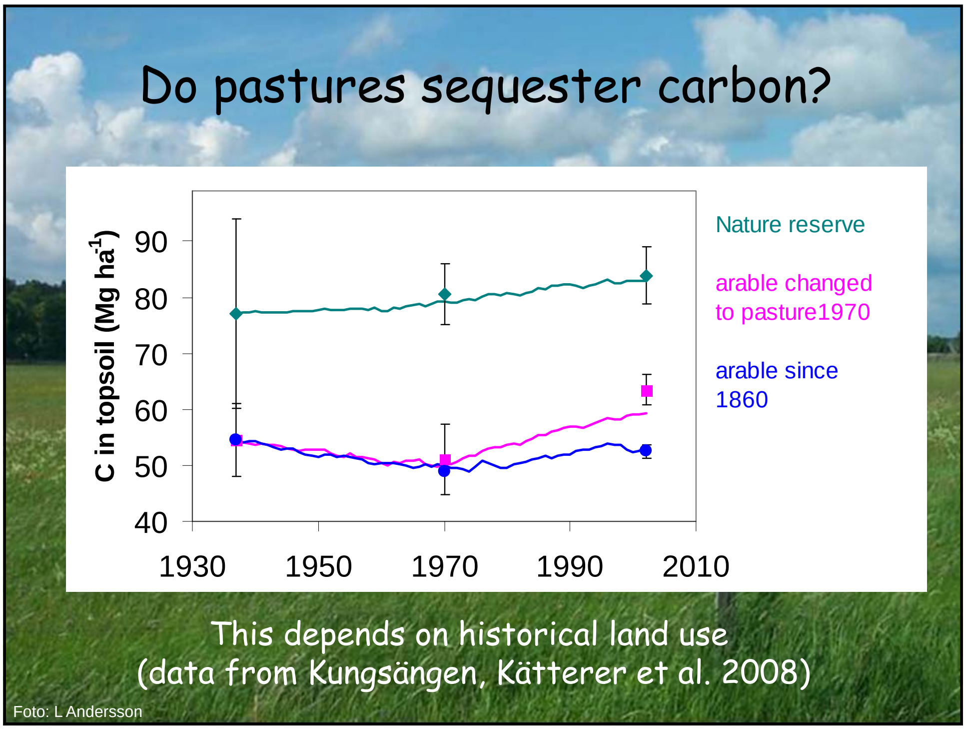
Production is governed by climate, soil properties and nutrient availability

Decomposition is mainly governed by:

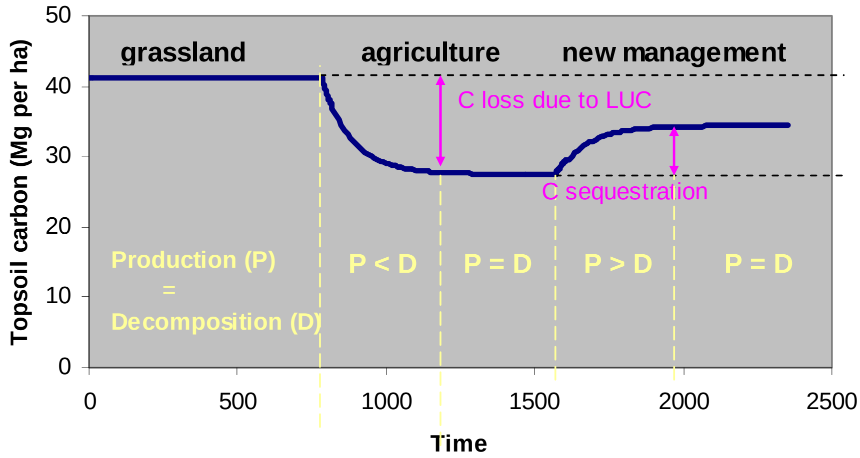
- Quantity and quality of organic material (land use and management
- Soil moisture and temperature




Impact of land use on SOC
Soil organic C remaining
(% of inititial C amount)
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
Years after conversion from grassland to
agriculture
Schlesinger 1991


Do pastures sequester carbon?
C in topsoil (Mg ha-1)
90
80
70
60
50
40
1930
1950
1970
1990
2010
Nature reserve
arable changed
to pasture1970
arable since
1860
This depends on historical land use
(data from Kungsängen, Kätterer et al. 2008)
Foto: L Andersson

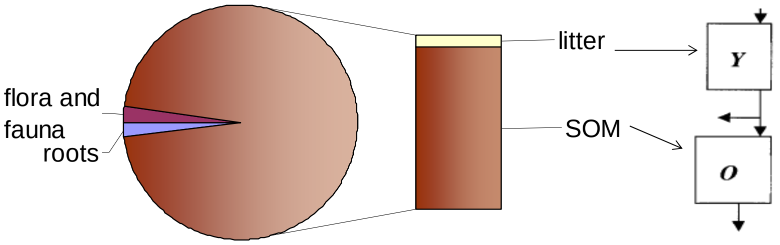
Soil C affected by land use change (LUC) and managment

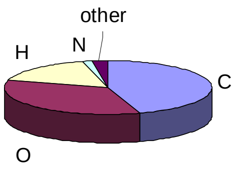


Strategies for C sequestration in agricultural soils

- High production
- No bare soil and more perennial vegetation (eg. catch crops, leys, hedgerows, agroforestry)
- Addition of waste products from e.g. bioenergi processing (biochar, sludges)
- More recalcitrant plant resdiues (breeding)
- Crops with high C allocation to roots
- Reduced tillage – under certain conditions (heavily debated)

Long-term field studies are valuable for calibrating C models

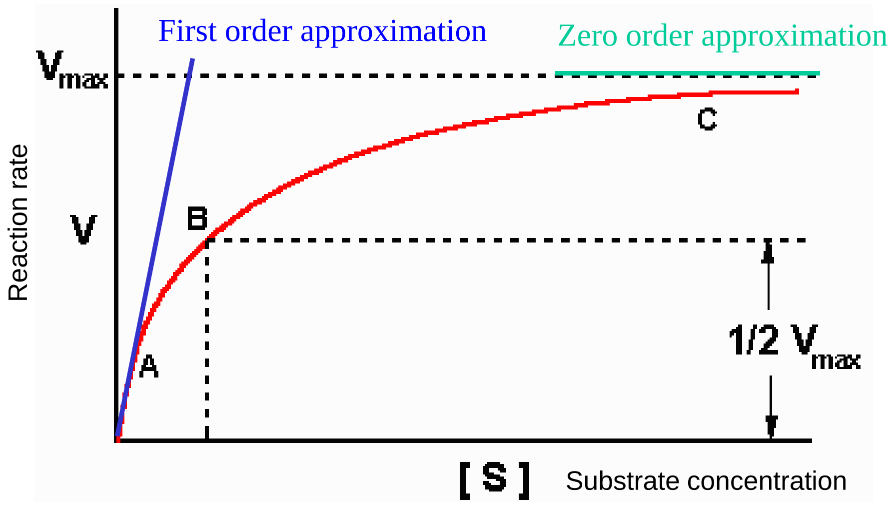




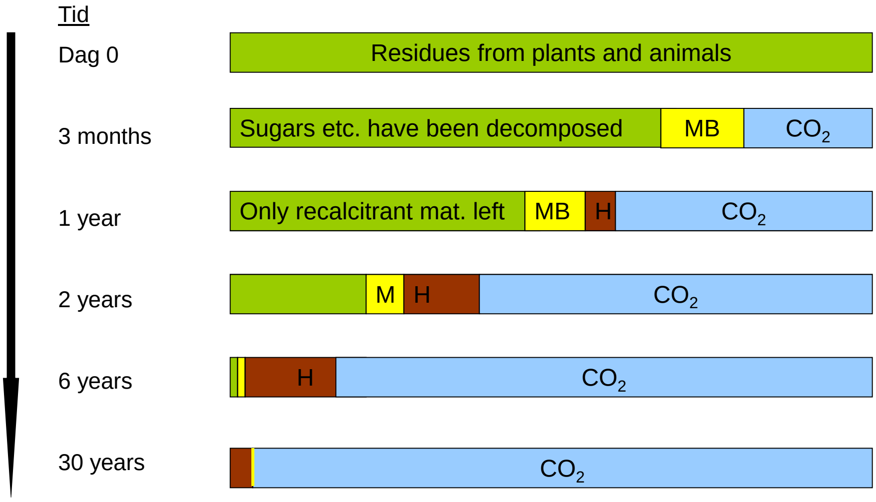
C concenctrations increase during decomposition, from about 40% in plant material to about 60% in humfied material.

SOM in arable soils contain about 50% C

A few CN-models assume Michaelis-Menten kinetics – first order kinetics is assumed in most CN-models

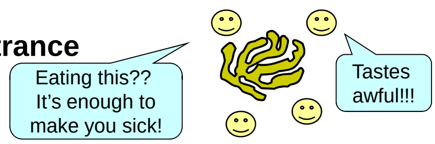


Residue decomposition and formation of SOM

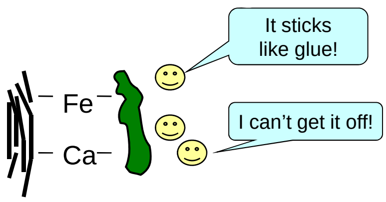


SOM stabilisation mechanisms

Biochemical Recalcitrance



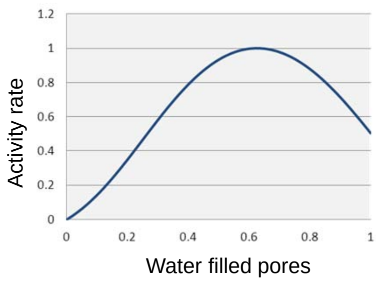
Chemical Stabilization

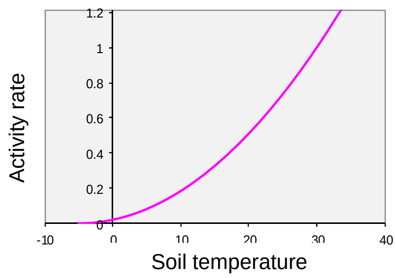


Physical Protection

Anke Herrmann

Decomposition rates are governed by soil temperature and water content



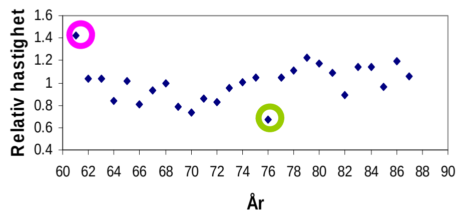


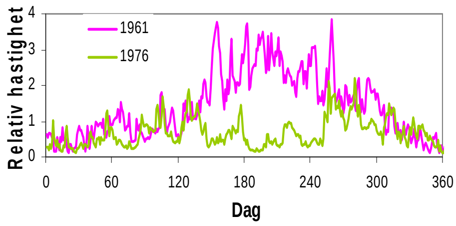
Variation in decomposition rates within and between years

Ex. Ultuna

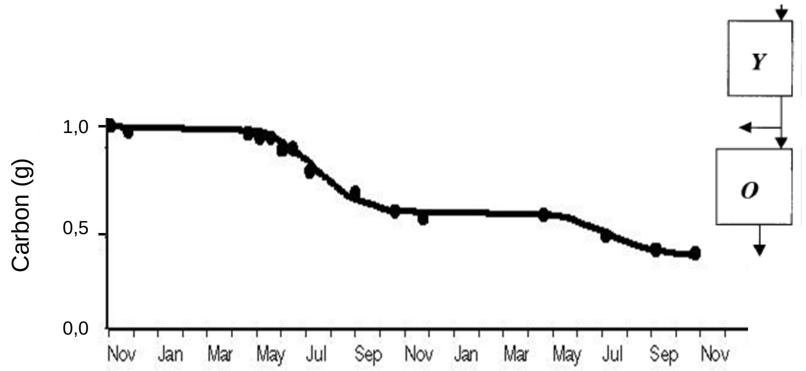
<u>Temperature (°C)</u>
Normal: 5,4
1961: 6,4
1976: 4,9

<u>Precipitation (mm)</u>
Normal: 520
1961: 571
1976: 412





Decomposition of barley straw in a field in Sweden – field measurements and output from a simple C model

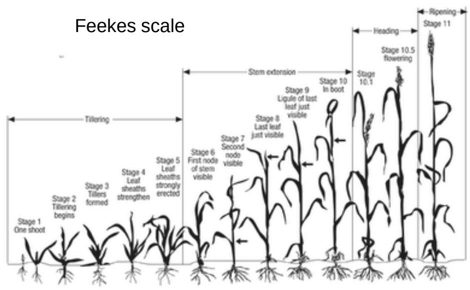


Kätterer et al., 2001 (data: ÅE, Andren & Paustian, 1987)

Dynamic modelling of N turnover in soil

N is usually driven by C since C-bounds provide energy to the heterotrphic community. These models are needed for predicting net N meralization

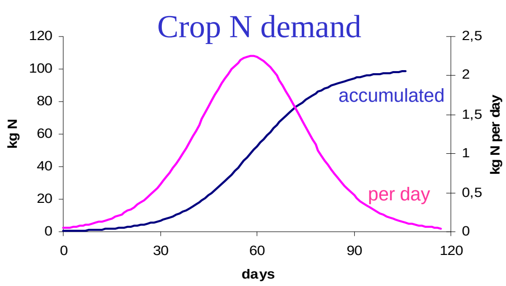
Feekes scale



For optimizing crop production

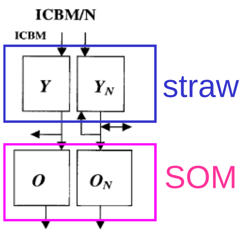
and

minimizing environmental impact, such as N leaching and GHG emissions (CO_2, N_2O)



Simple dynamic model for estimating N mineralization

Ex.: soil with/without addition of straw



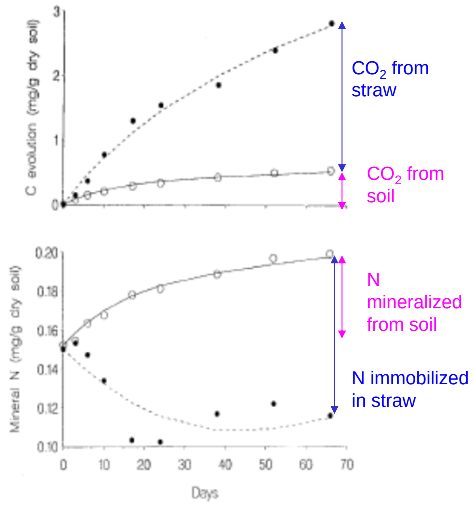
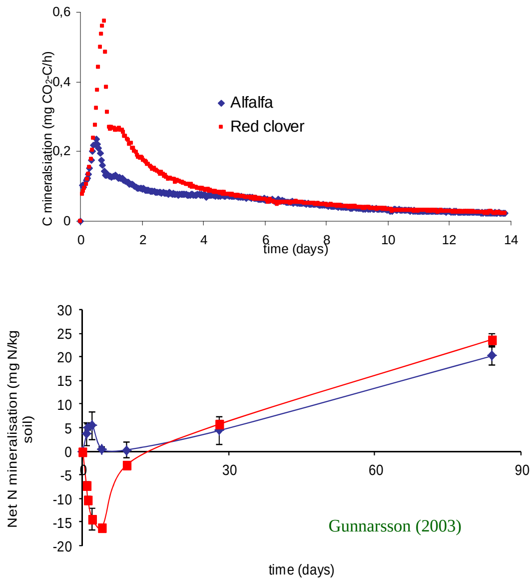


Fig. 5. Measured (symbols) and modelled (lines) dynamics of accumulated CO_2-C evolution and nitrogen mineralisation/immobilisation from the Nåntuna soil as incubated at about 20°C (Jansson, 1958). Treatments were: with straw (●; -----) and without straw (○; ——). See Table 1 for initial and parameter values.

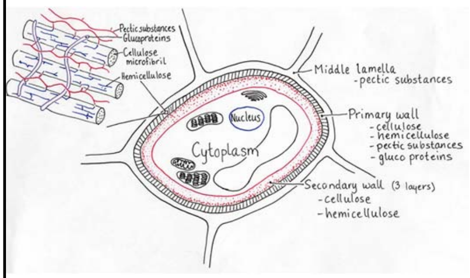
Kätterer & Andrén, 2001

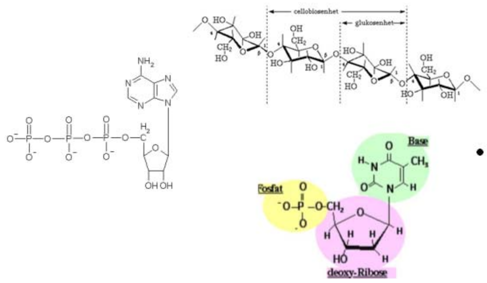
C and N dynamics in decomposing legumes with C/N=16 in both



C/N is often a good indicator for N delivery in a medium-term perspective

Several dimensions of "substrate quality"





- **Physical structure** – particle size
- **Type of polymer** – production of exo-enzymes
- **Chemical properties –** hydrophobicity, lignin to N ratio
- **Chemical bonds** – e.g. peptide- or aromatic N

Toxicity – phenolic substances (produced by plants), antibiotics produced by fungi

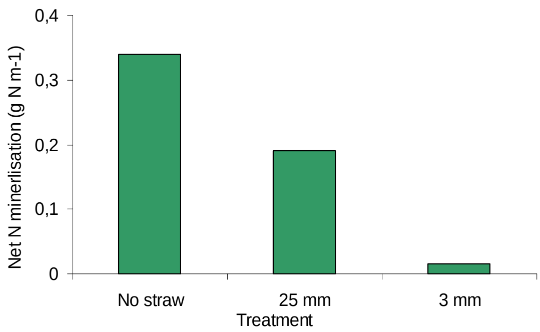
- **Nutrient concentrations**

Net N mineralisation influenced by particle size

Decomposition rate increases with decreasing particle size:

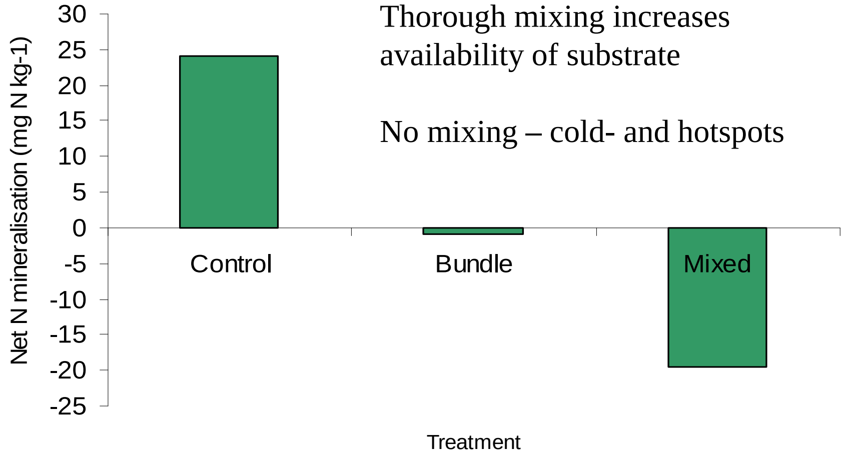
Small particles – large surfaces and higher levels of soluble organic material

Fast-growing microorgansims causing N immobilization



From: Ambus P. and Jensen E.S. (2000)

Net N mineralisation influenced by spatial distribution



Thorough mixing increases availability of substrate

No mixing – cold- and hotspots

From: Ambus P. and Jensen E.S. (2000)

Spatial distribution in the soil – plants and microbes are competing for N

Distance larger than 6 mm:
Roots - advantage
Bacteria - disadvantage

From: Jingguo & Bakken (1997)

Summary

- Short-term effects of organic amendments on yield are determined by their nutrient content and decomposability
- C/N is often a good indicator for the N fertilizer equivalent of organic amandments.
- Long-term effects are more determined by their effect on SOM builtup (humification coefficient)
  - directly and
  - indirectly, by stimulating plant growth which results

in higher C input to soil

- Roots contribute relatively more to soil C stocks than corresponding input from above-ground sources
- 1 kg C is sequestered for each kg N applied

Summary cont.

- Soils play a major role in the global C cycle
- Agricultural soils are the major source of N2O emissions
- SOM affects many soil properties
- Decompositon rates depend on substrate quality and abiotic conditions
- Most dynamic models describe decomposition as a first order rate process
- The complexity of models needed for describing soil N-dynamics depends on the time resolution needed and how general the model should be