Carbon sequestration in grasslands State of the art

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Carbon sequestration in grasslands
State of the art

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ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

Outline

1. Introduction: the terrestrial carbon sink

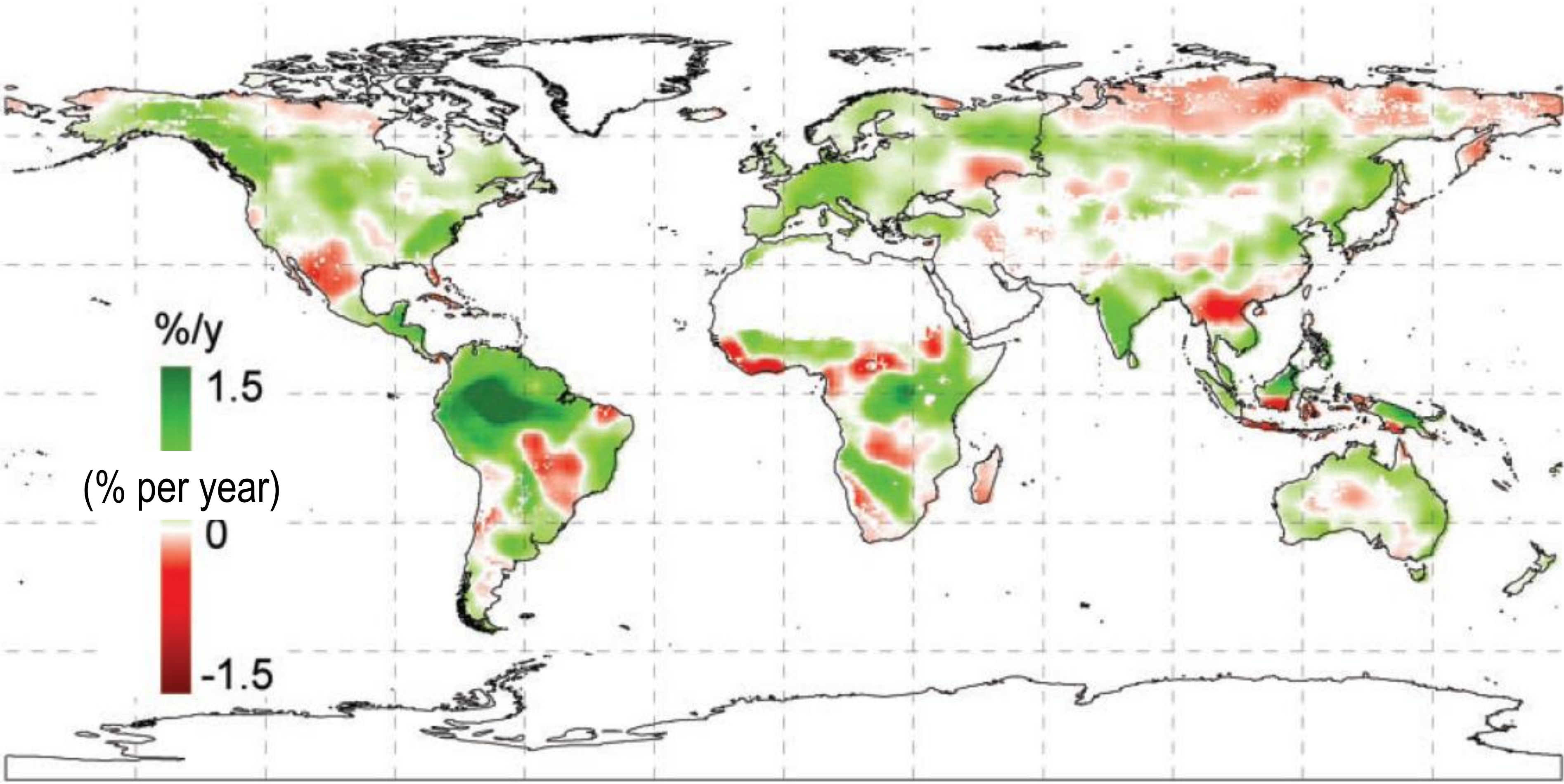
2. Carbon sequestration in European grasslands

3. Carbon sequestration in the context of GHG balance

4. Vulnerability of carbon stocks to climate change and biodiversity loss

5. Carbon sequestration options for livestock farms

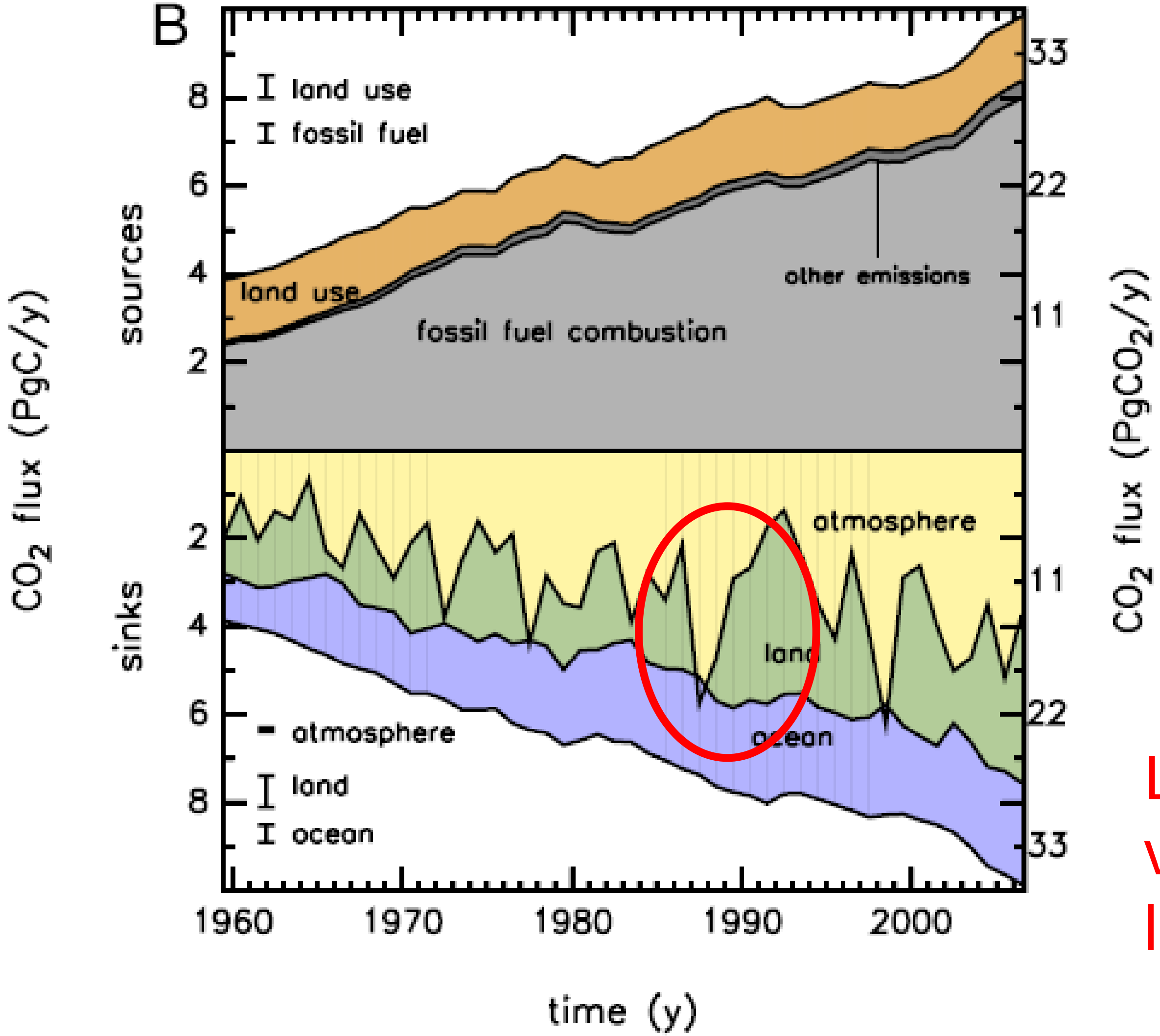
Greening of land
(1982-1999)



Secular increase in ecosystem primary productivity from satellite (NDVI) over the past 25 years

(Nemani et al., Science 2003)

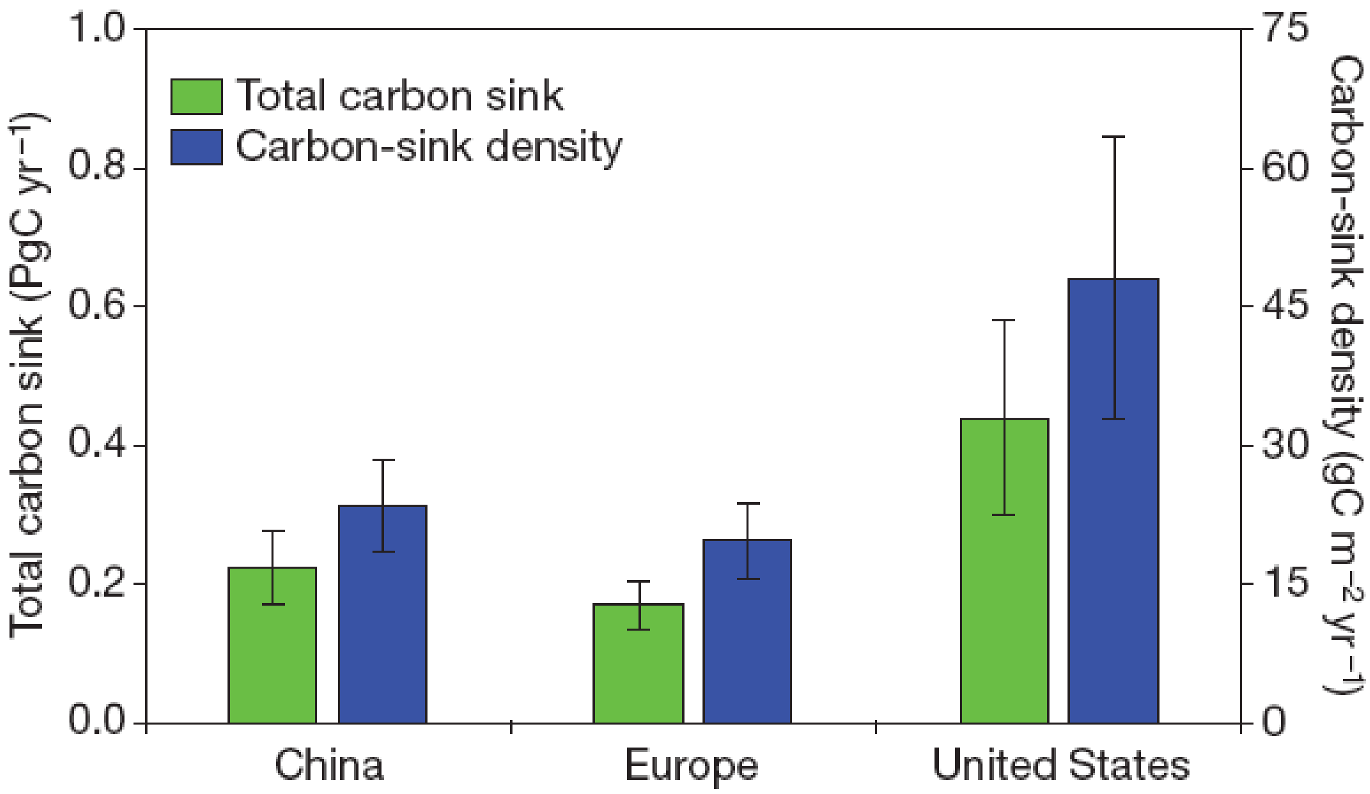
Land and oceans store carbon



Large interannual variability in global land C sink

(Canadell et al.,2007, PNAS)

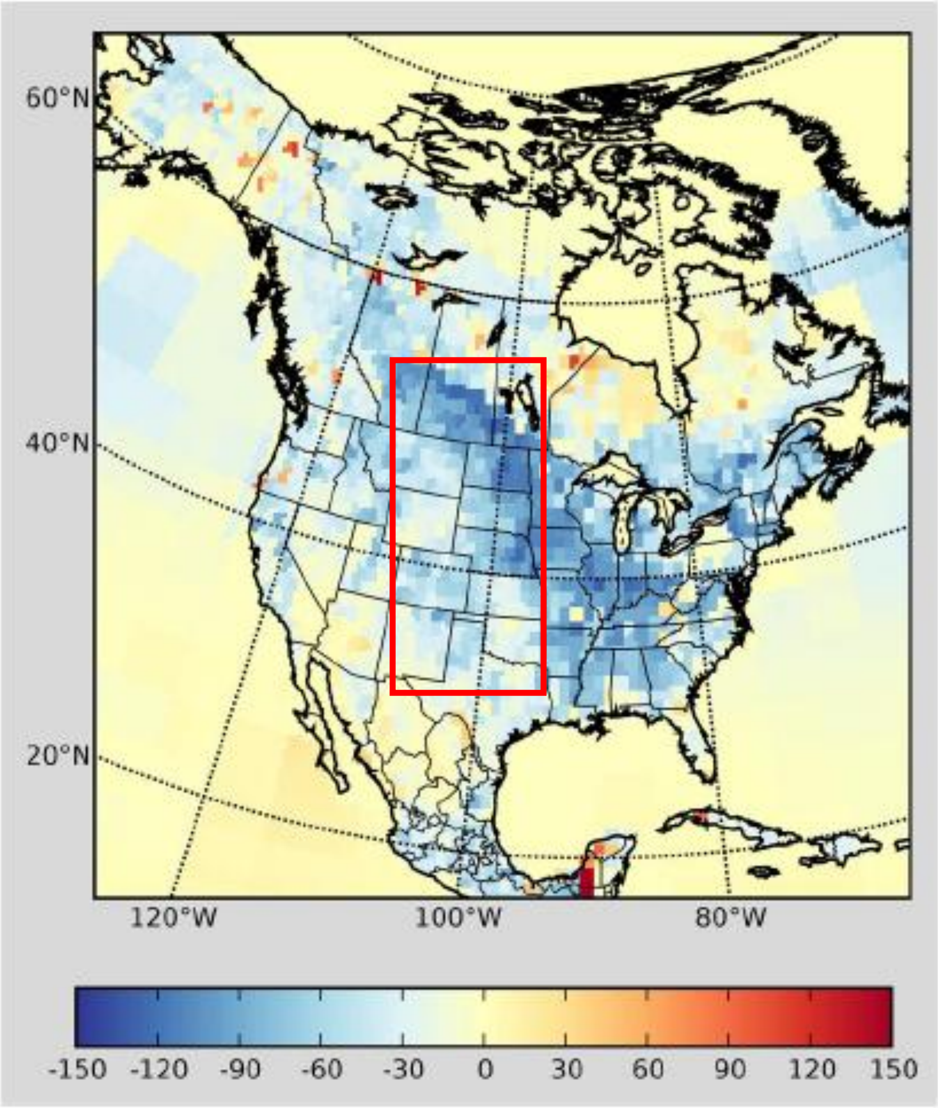
Carbon sink in China, Europe and United States



From atmospheric and ecosystem measurements

(Piao et al., Nature, 2009)

Detailed carbon sink map in Northern America

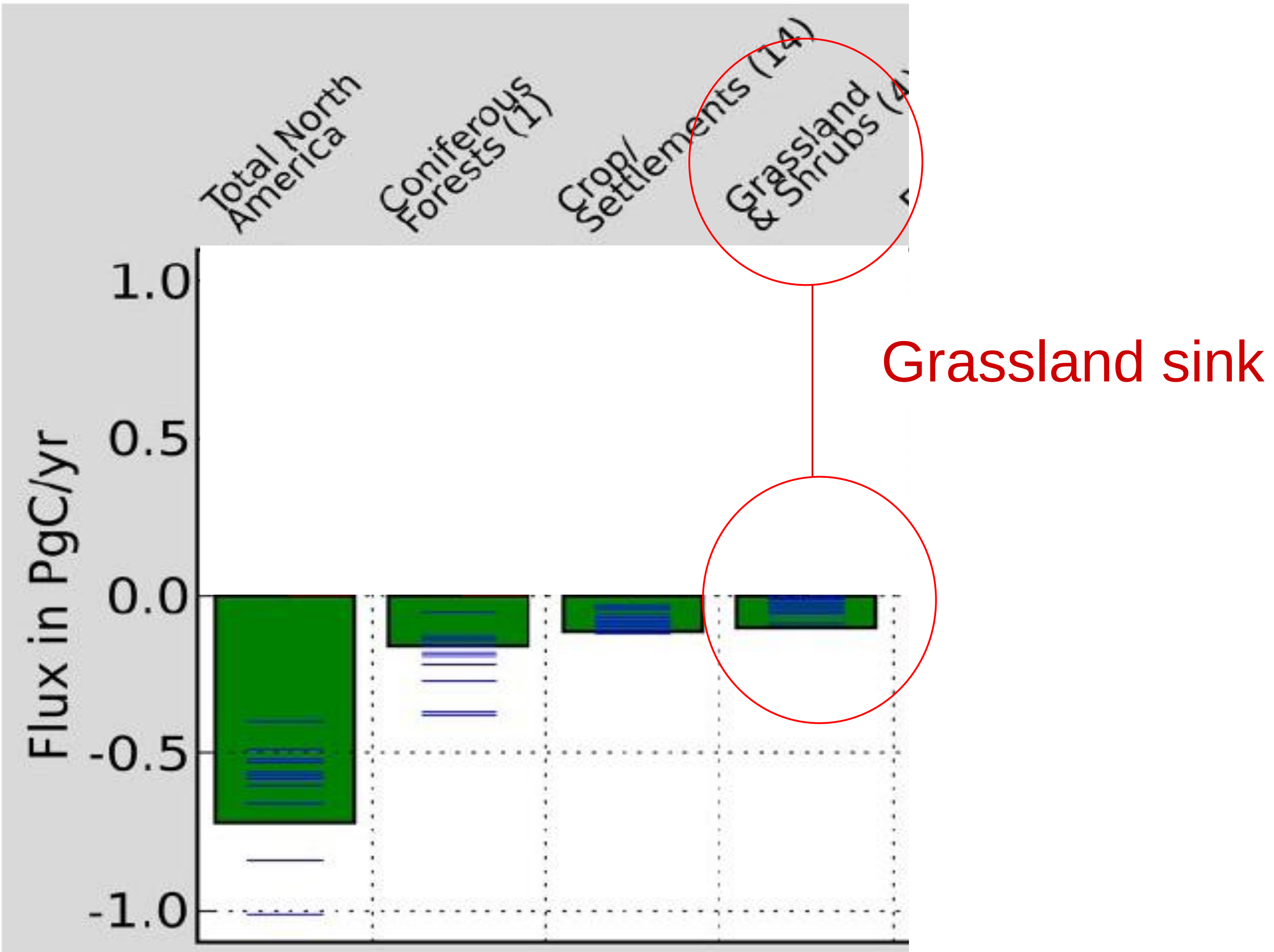


Grasslands
In N. America

(Peters et al., PNAS, 2007)

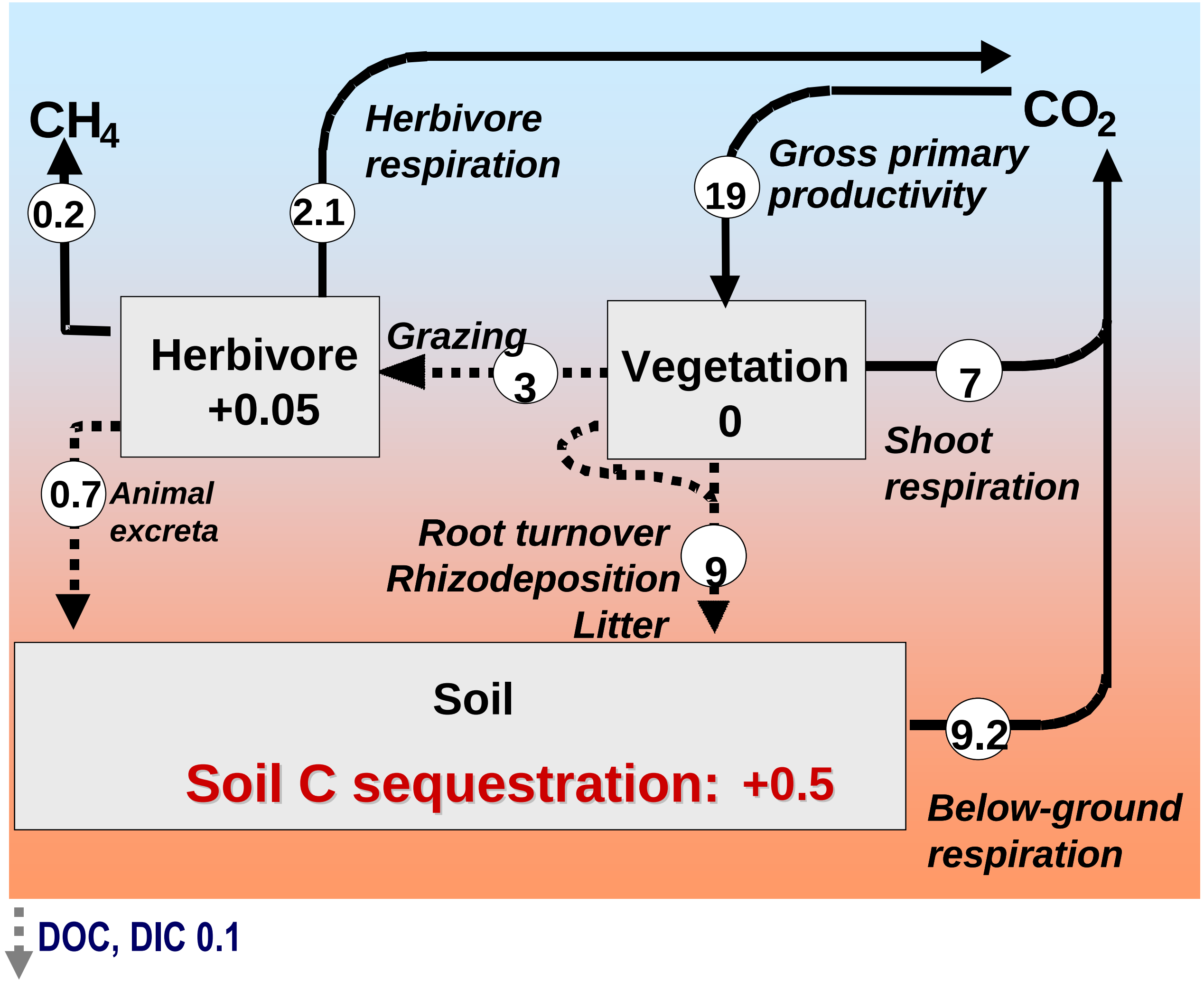
‘CarbonTracker’: atmospheric modelling

Land carbon sink in Northern America



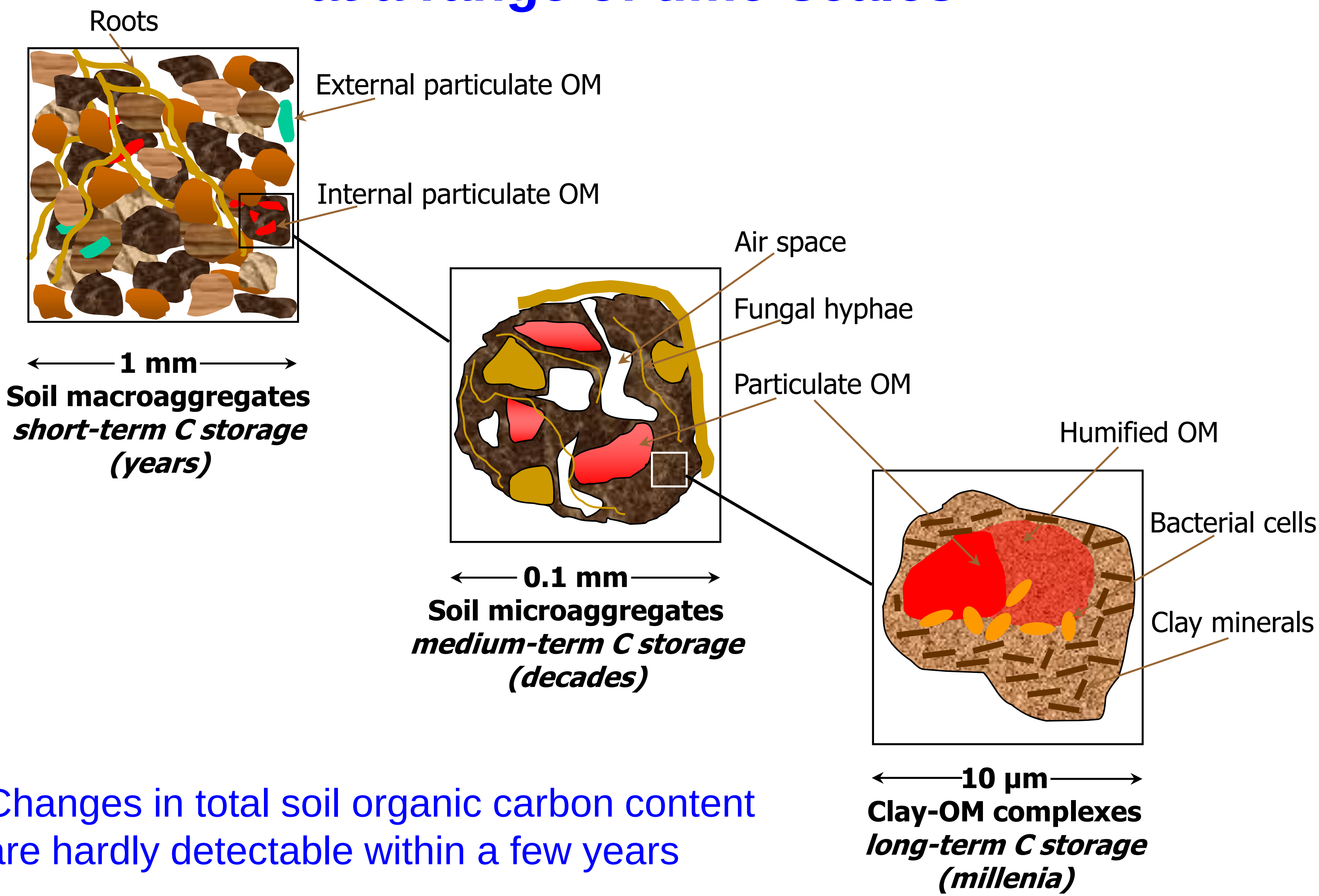
(Peters et al., 2007, PNAS)

C sequestration in a temperate pasture
(tC ha^{-1} yr^{-1})



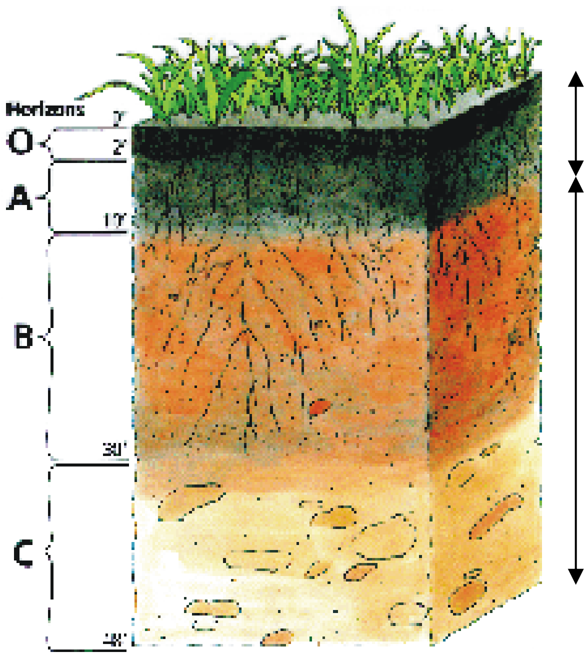
Sown grassland with intensive grazing (Soussana et al., Soil Use Manag., 2004)

Soil processes leading to carbon storage at a range of time-scales



Changes in total soil organic carbon content are hardly detectable within a few years

How stable is organic carbon?
Comparing deep and top soil



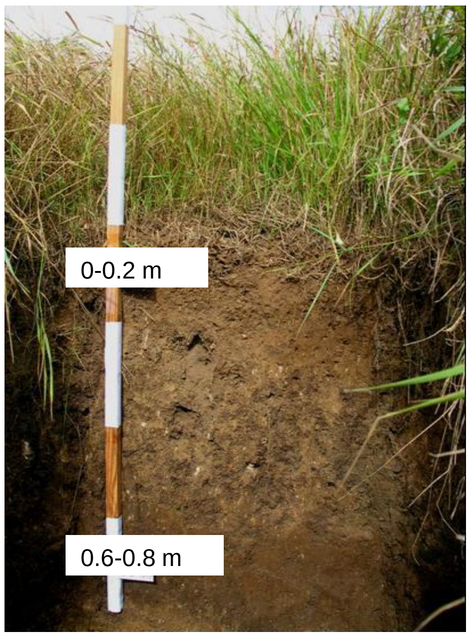
	Reservoir of carbon (GtC)	Residence time (years)
0-0,2 m	600	10-300 yrs
0,2-3 m	1700	1000-15000 yrs Highly stable deep carbon

Is this large pool of carbon going to react to global change and accelerate the rise of atmospheric CO_2?

(Fontaine et al., Nature 2007)

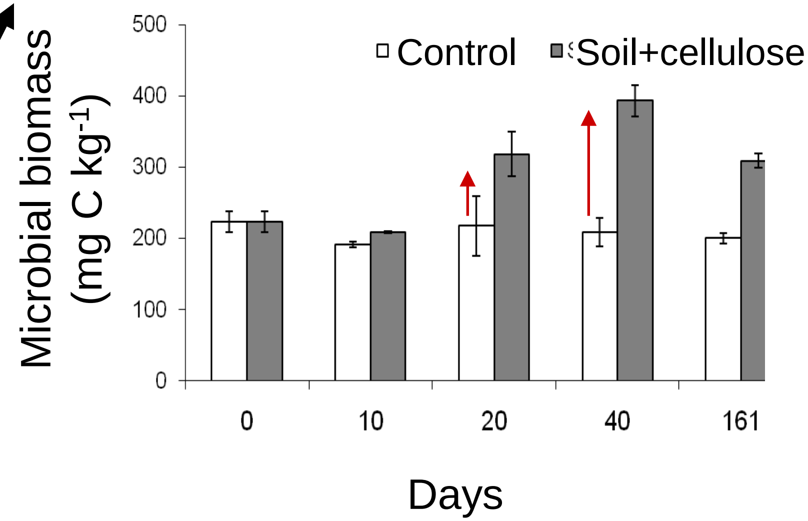
Effect of fresh C supply to deep microbes.

Cellulose (labeled with ^{13}C, ^{14}C)



Picture of the studied profile.

Stimulation of microbial growth



Reactivation of decomposition of 2600 yr old soil C (priming effect).

Without supply of fresh C (energy) for microbes, deep carbon is stable

(Fontaine et al., Nature 2007)

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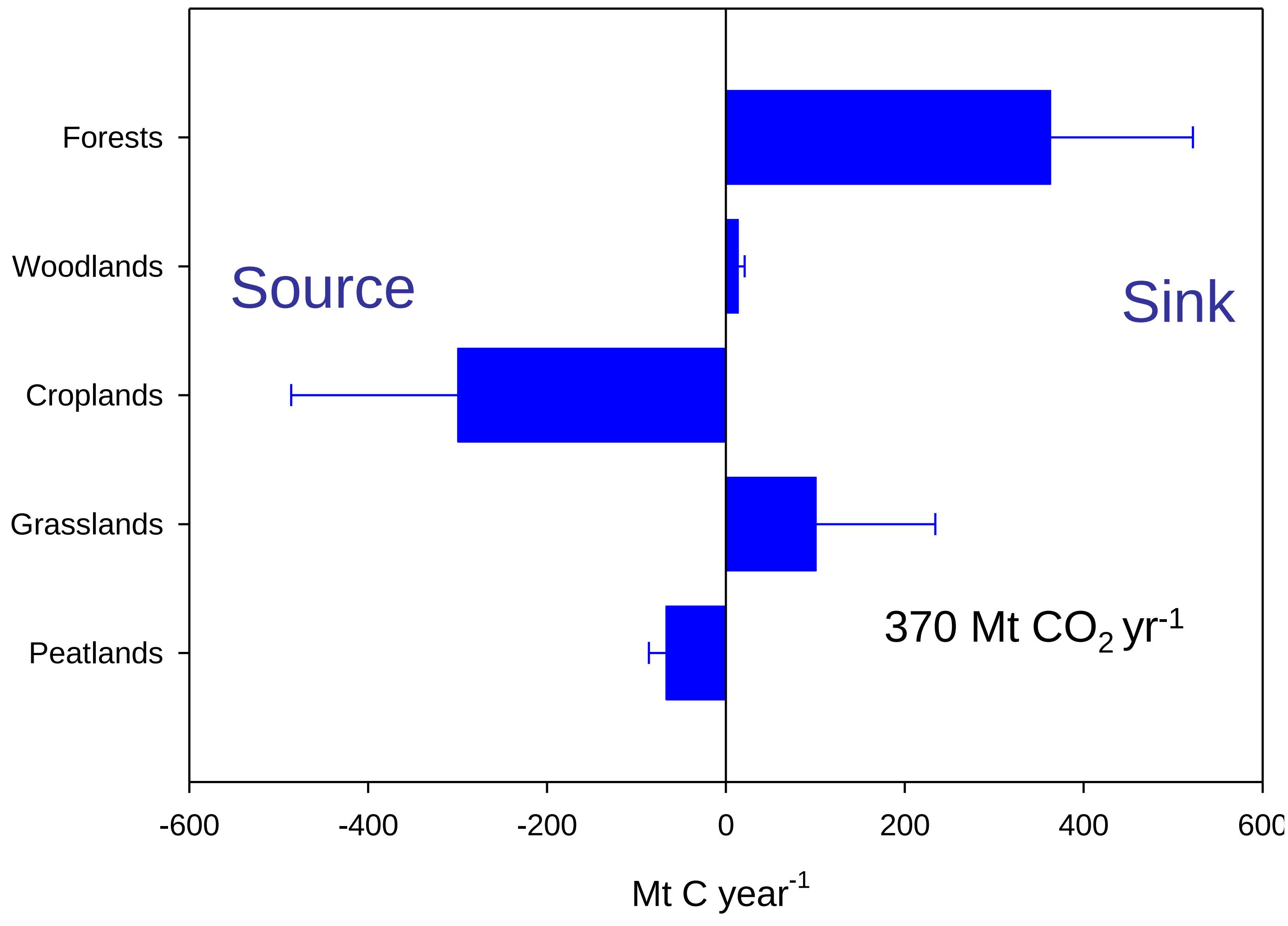
Land carbon sinks and sources in Europe

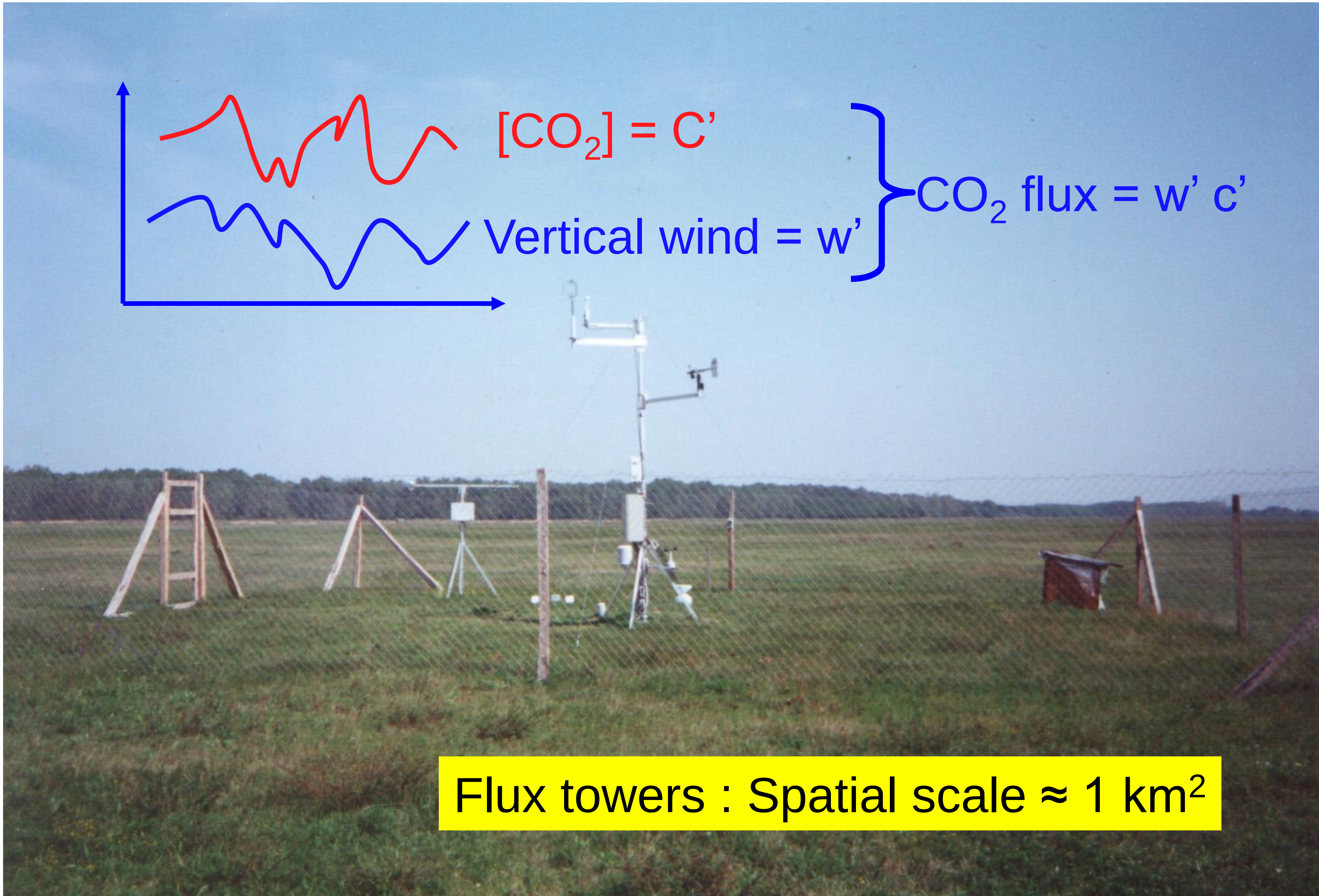
(Janssens et al. Science, 2003).



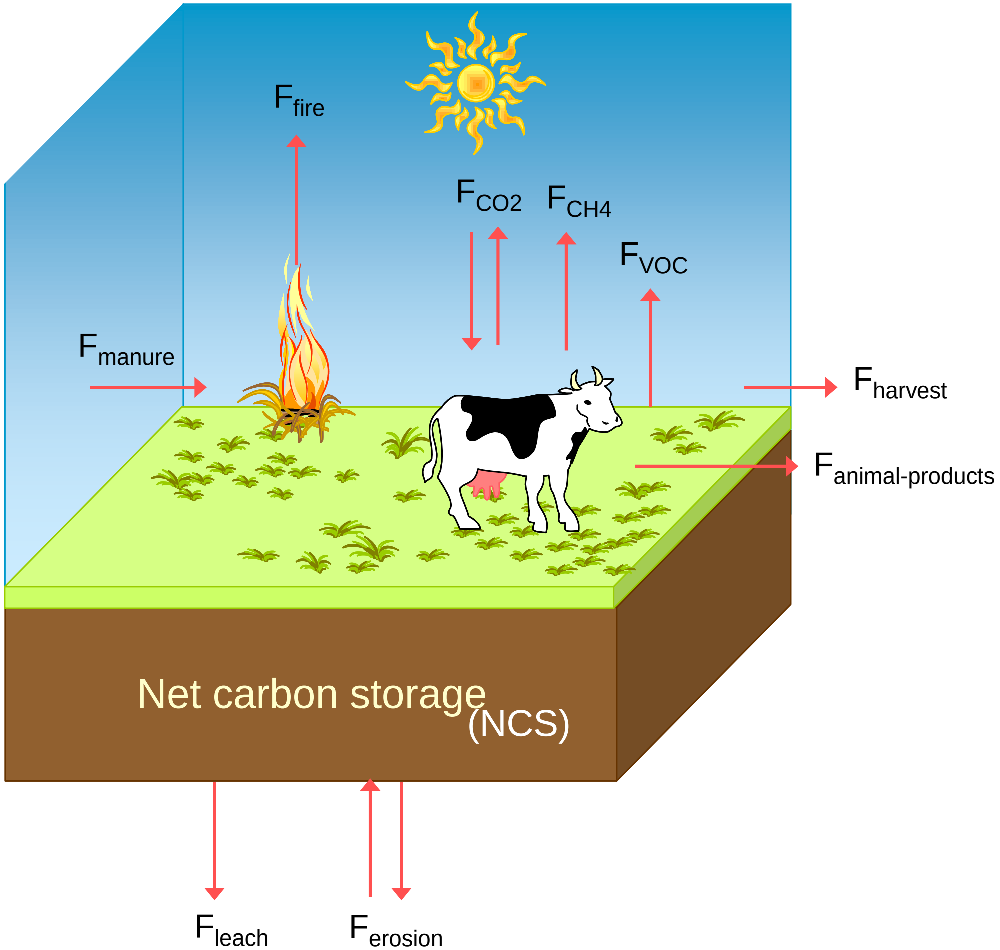
Estimated carbon sink: 7-11 % of fossil fuel emissions

Geographic Europe

The eddy covariance method for measuring CO_2 fluxes



C fluxes in a grassland ecosystem



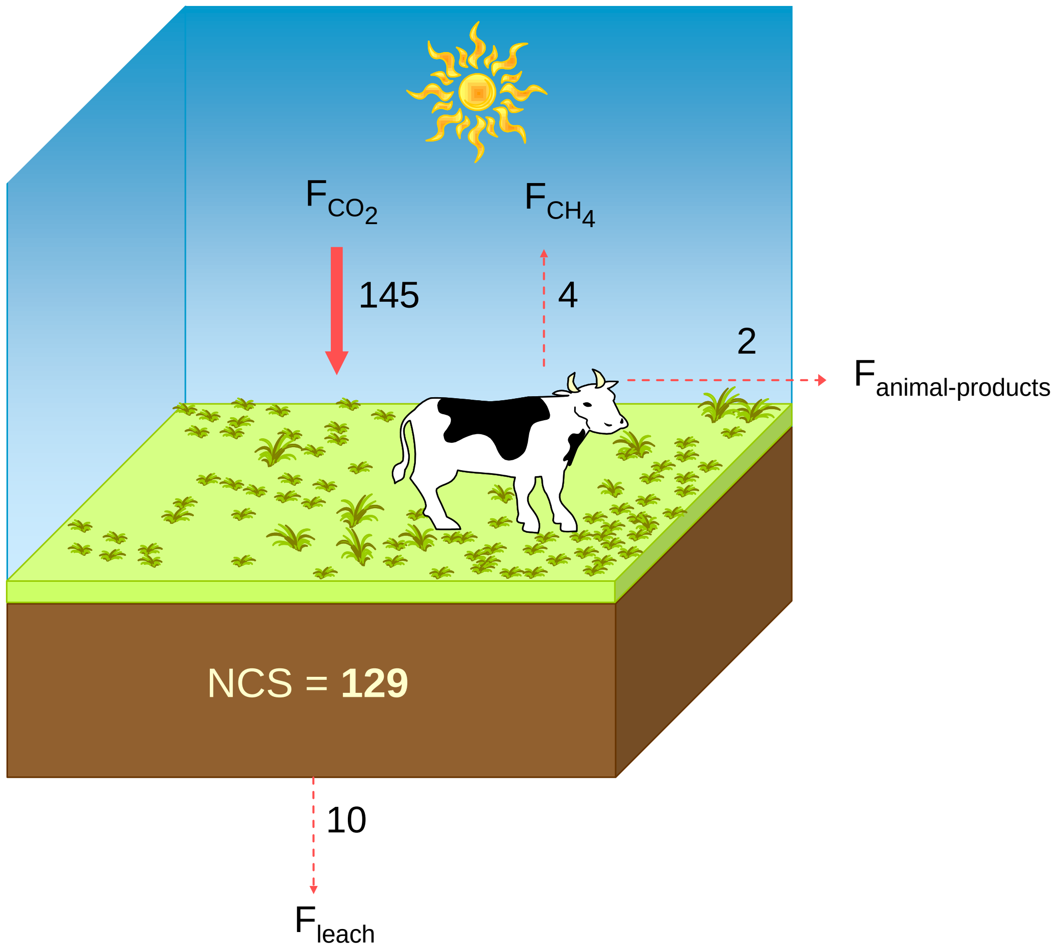
$$NCS = (F_{CO2} - F_{CH4\text{-}C} - F_{VOC} - F_{fire}) + (F_{manure} - F_{harvest} - F_{animal\text{-}products}) - (F_{leach} + F_{erosion})$$

Simplified balance in a temperate managed system:

$$NCS = (F_{CO2} - F_{CH4\text{-}C}) + (F_{manure} - F_{harvest} - F_{animal\text{-}products}) - F_{leach}$$

(Soussana and Tallec, 2009, Animal, in press)

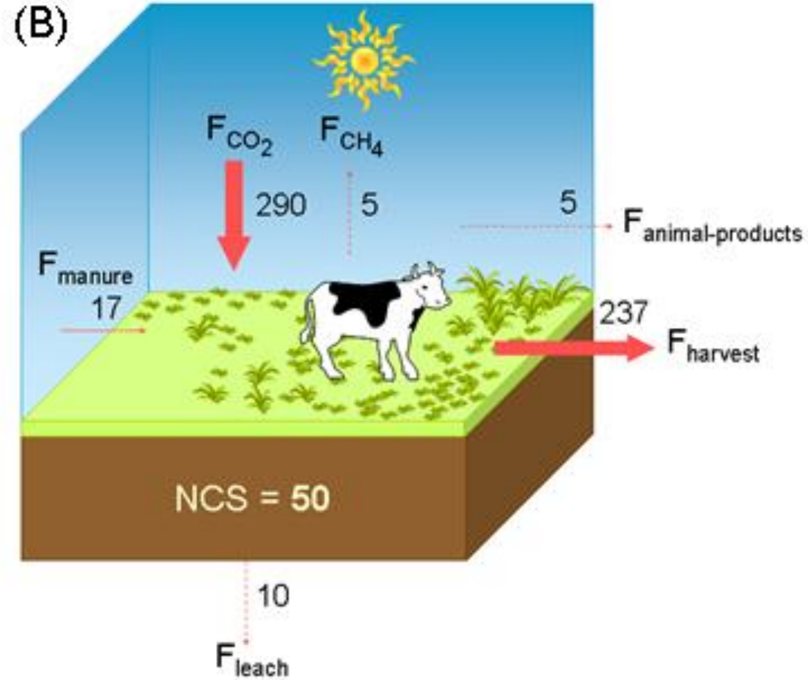
C sequestration (NCS) at grazed only European sites (g C m^{-2} yr^{-1})

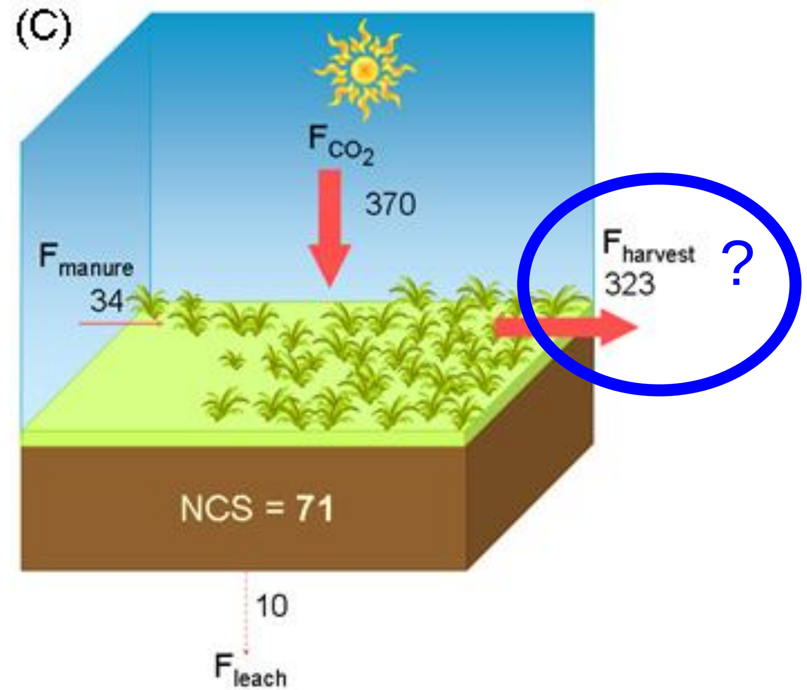


Mean of 2 sites
(Soussana et al., 2007, AGEE; Soussana & Tallec, 2009, Animal)

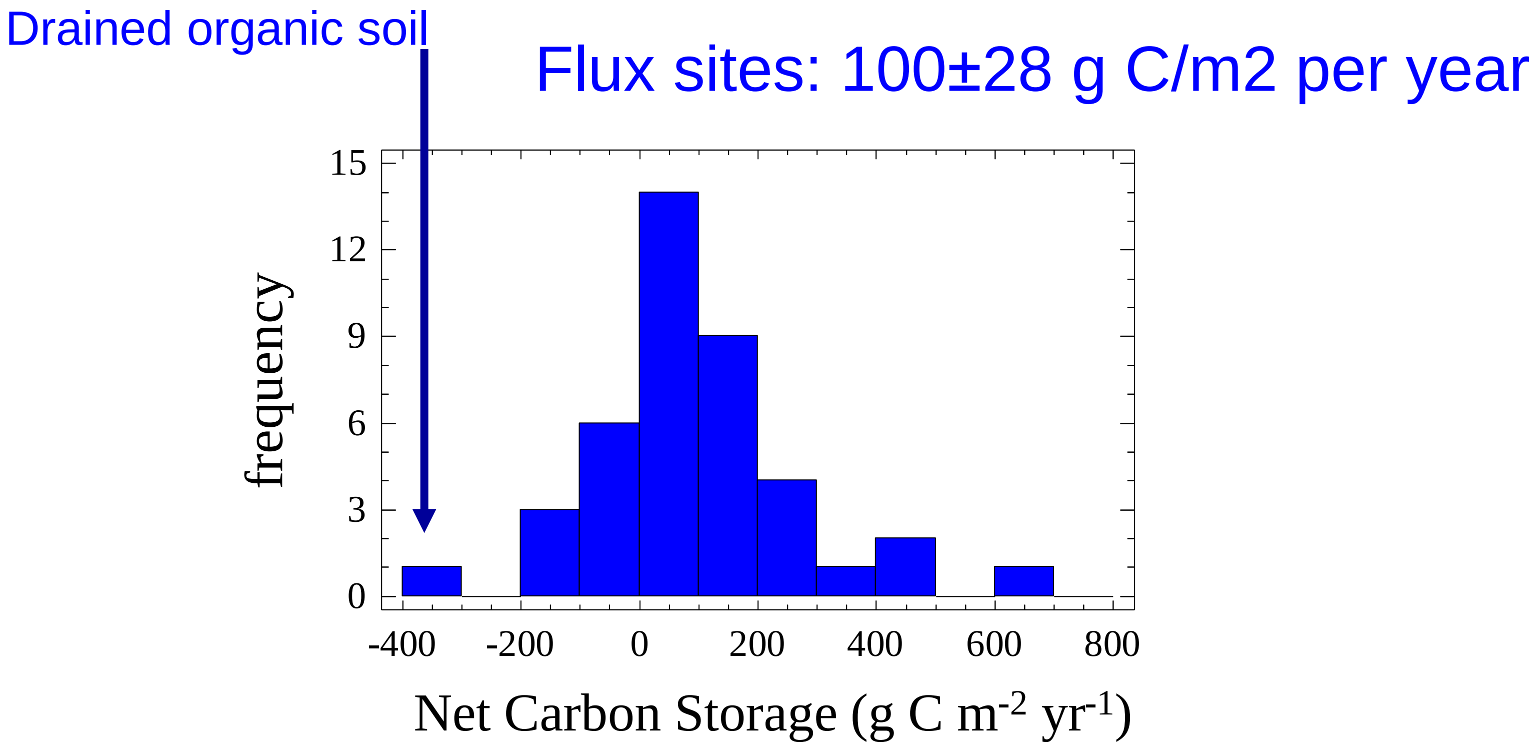
C sequestration (NCS) at cut European sites

(g C m^{-2} yr^{-1})



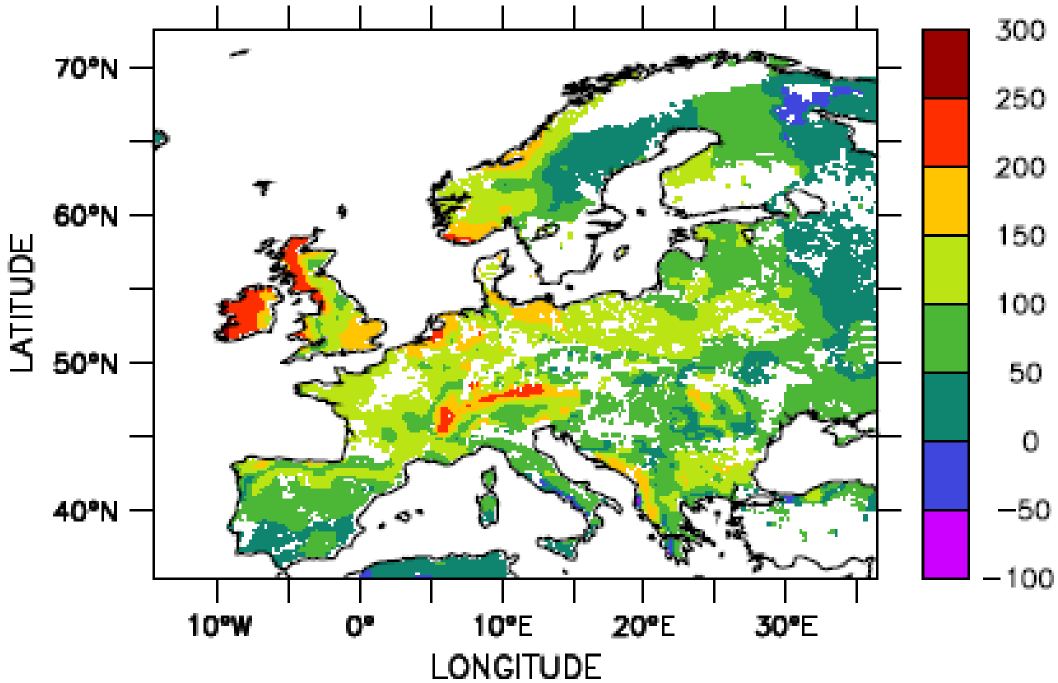


Carbon sequestration in grasslands: range of estimates



(Soussana and Tallec, Animal, in press; Soussana et al., in prep.)

A first estimate of carbon sequestration in European grasslands (data based upscaling)



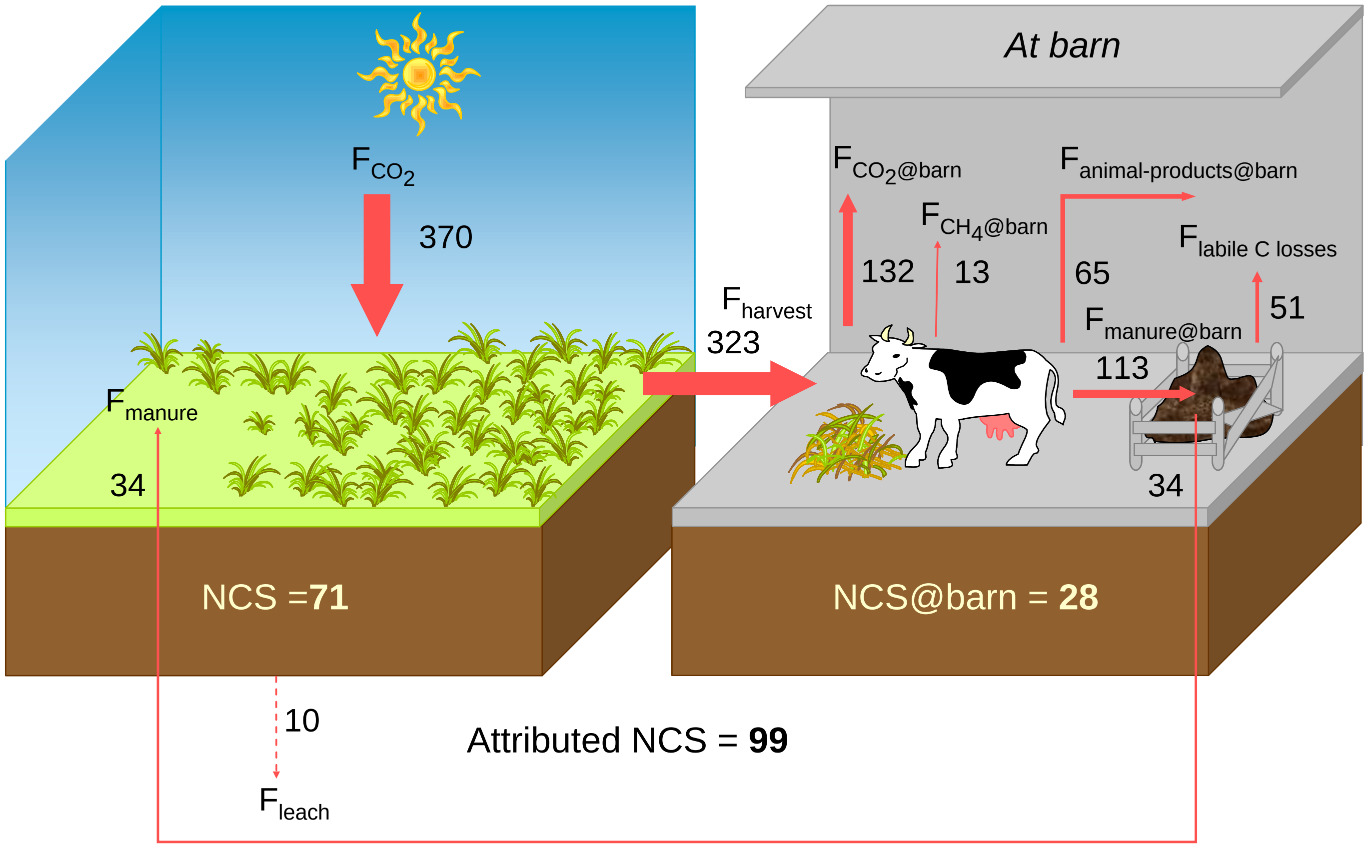
NBP (gC m−2)

C sequestration reaches 6 % of gross photosynthesis, similar to forests

Direct plus indirect emissions of N_2O and CH_4 lead to a 45 % trade-off

(Soussana et al., in prep.)

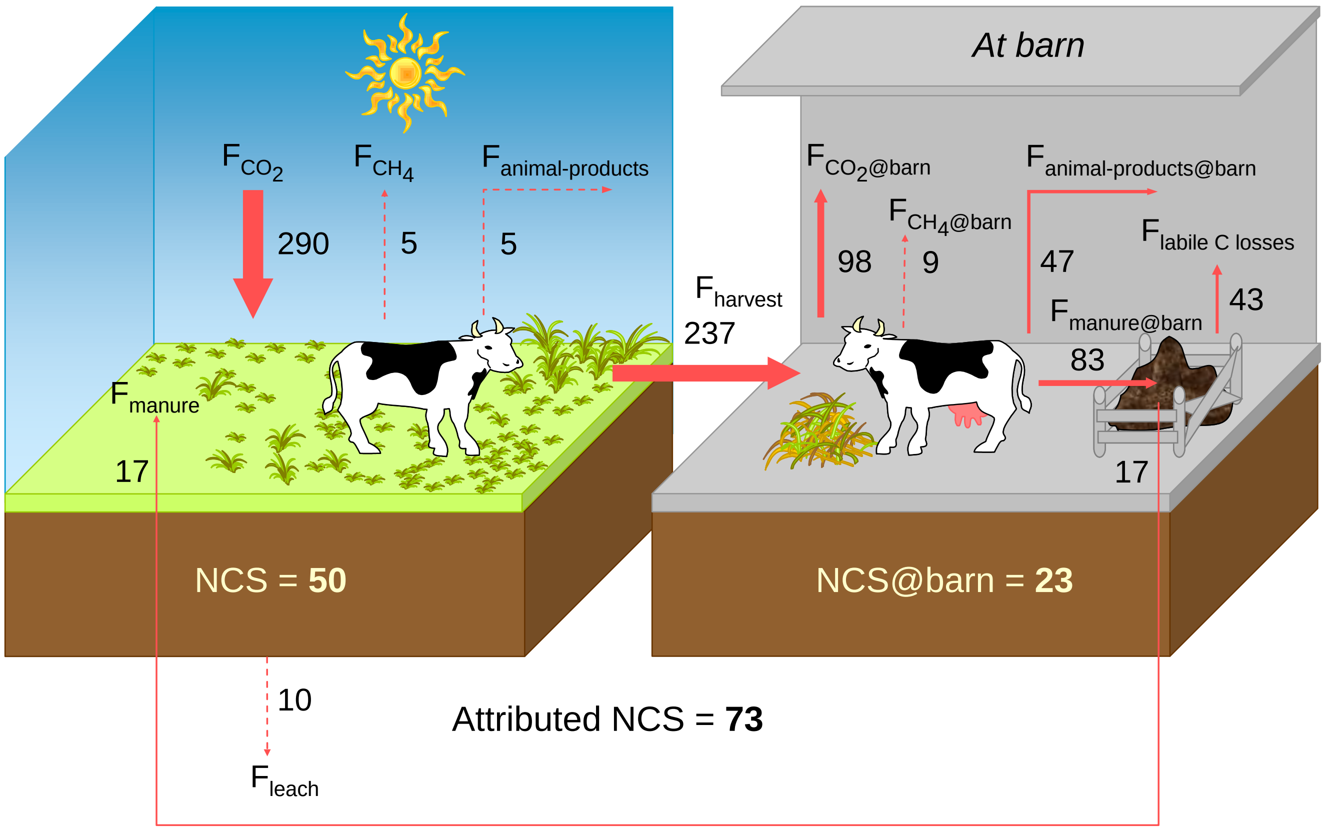
Fate of harvested C at cut sites
($g\ C\ m^{-2}\ yr^{-1}$)



$$Att\text{-}NCS = NCS + NCS_{@barn} = NCS + f_{humif}\ Max[0, (1-f_{diges})F_{harvest} - F_{manure}]$$

Mean of 3 sites
(Soussana et al., 2007, AGEE; Soussana & Tallec, 2009, Animal)

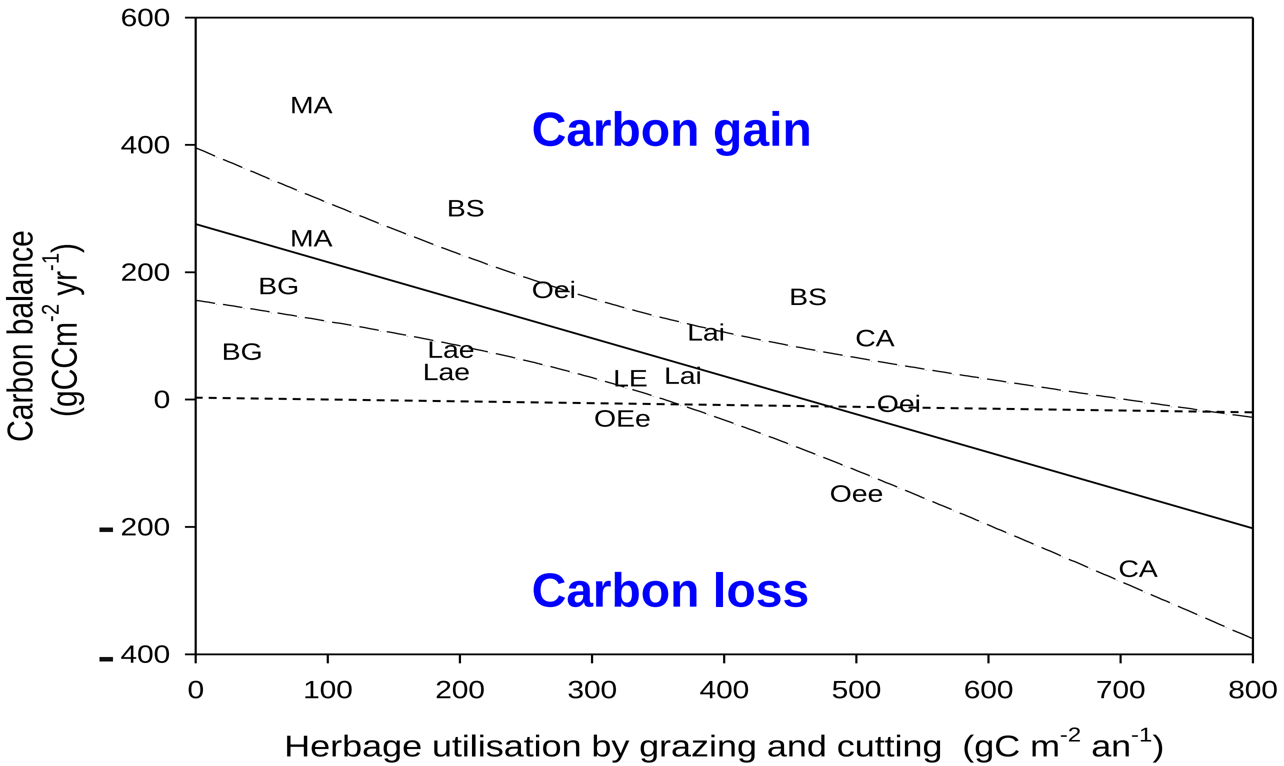
Fate of harvested C at cut and grazed sites
(g C m^{-2} yr^{-1})



Mean of 4 sites

(Soussana et al., 2007, AGEE; Soussana & Tallec, 2009, Animal)

Carbon sequestration (NCS) at 10 European grassland sites

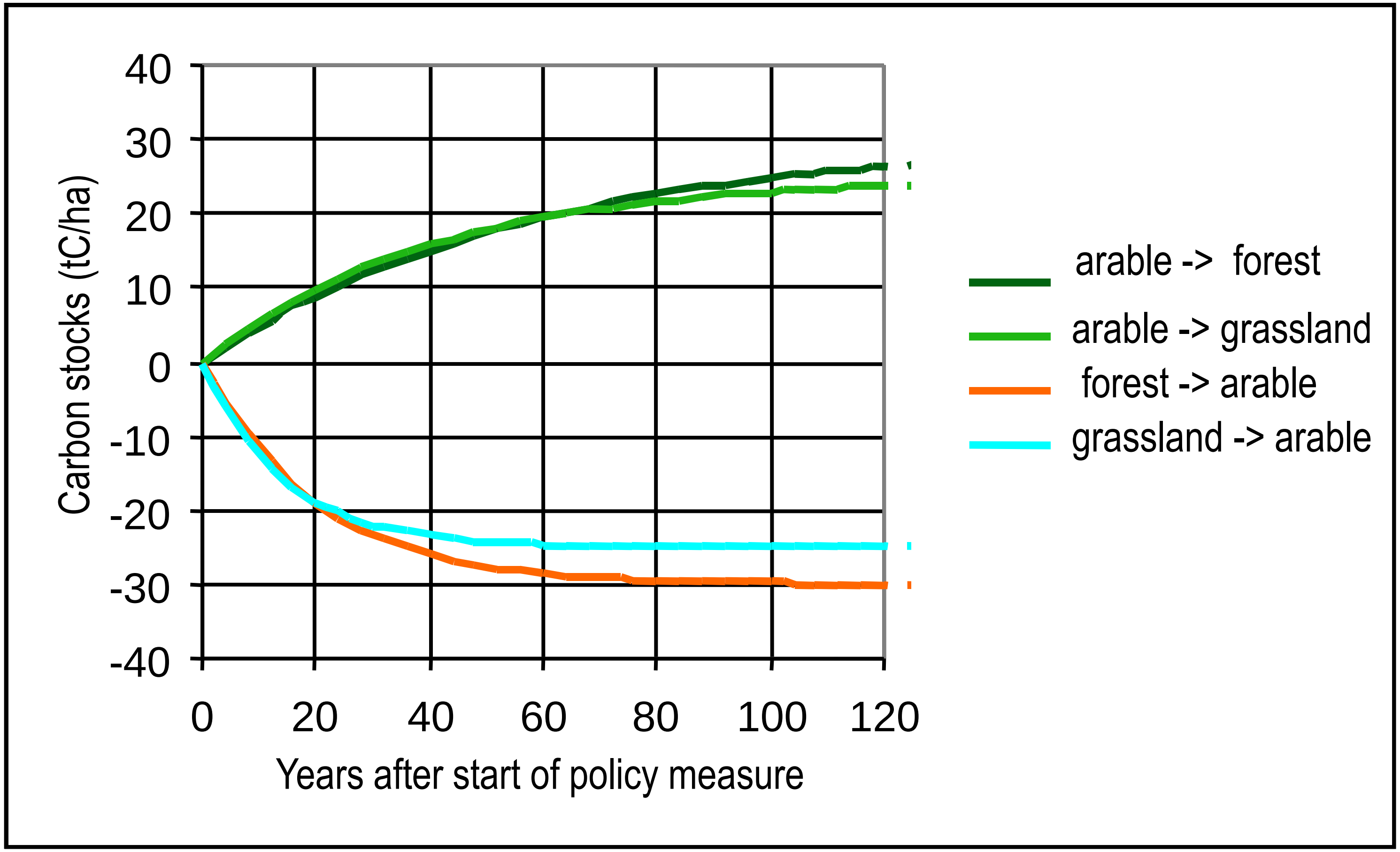


- The less carbon is used, the more is returned to the soil, which increases C sequestration

- Nitrogen supply also favours carbon sequestration

(Soussana et al. Agriculture, Ecosys. Environment, 2007)

Land use change effects on soil carbon stocks



Carbon in soils: slow in and fast out!

(INRA, 2002)

How to increase soil carbon stock

Increase C inputs

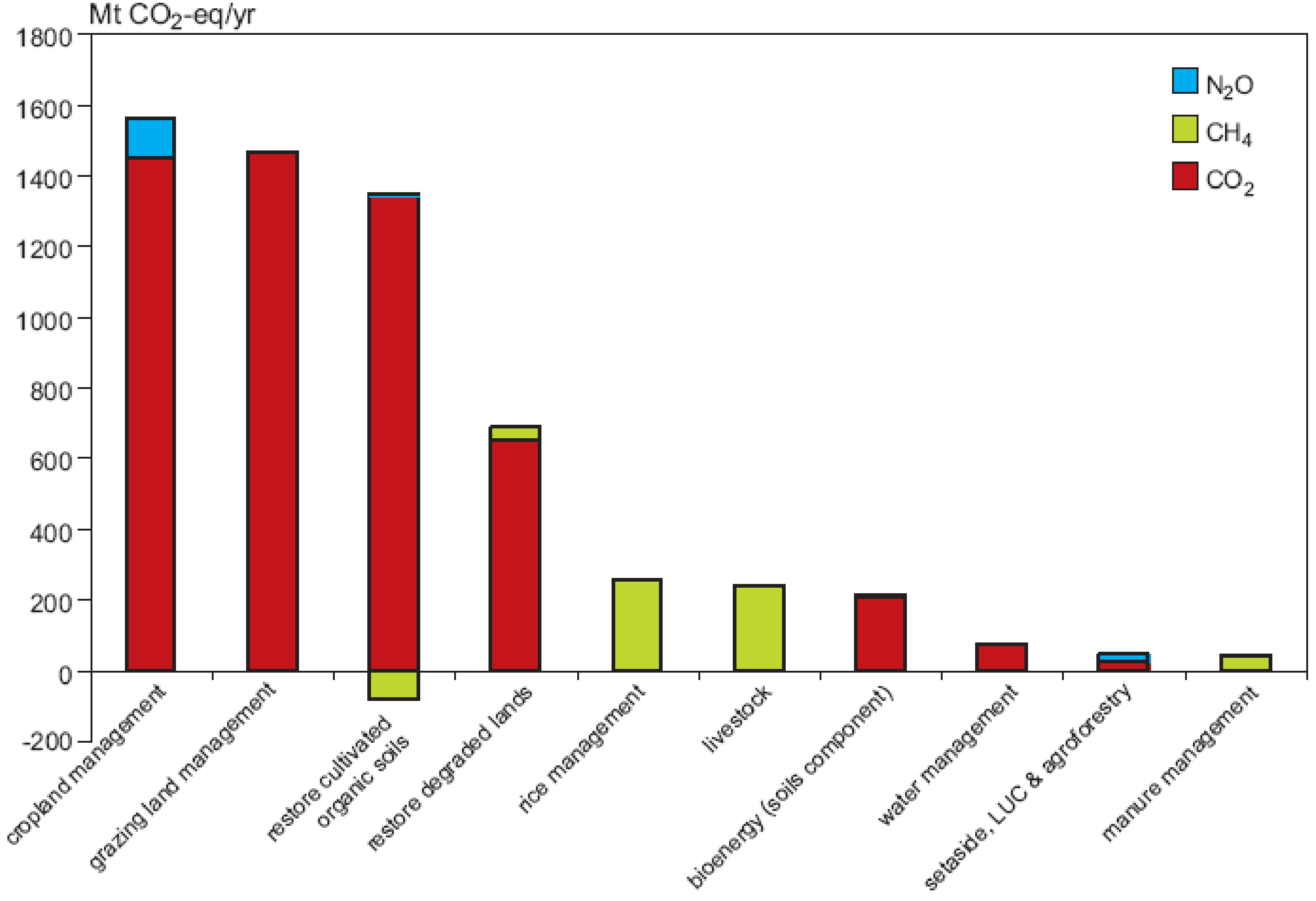
1. Increase biomass
   - Forage productivity
   - Species selection
   - Legumes, fertilizers
   - Irrigation
   - Grass/legume mix
2. Change from short-term to permanent grassland
3. Reduced cutting, avoid overgrazing
4. Introduce earthworms

Soil Organic Matter (C,N)

Decrease C losses

1. Avoid ploughing up permanent grasslands
2. Conversion from arable to grassland & from short duration leys to permanent grassland
3. Reduce cutting and grazing
4. Reduce fire, leaching, erosion & mineralisation
5. Improve soil structure

Global technical mitigation potential by 2030 of each agricultural management practice



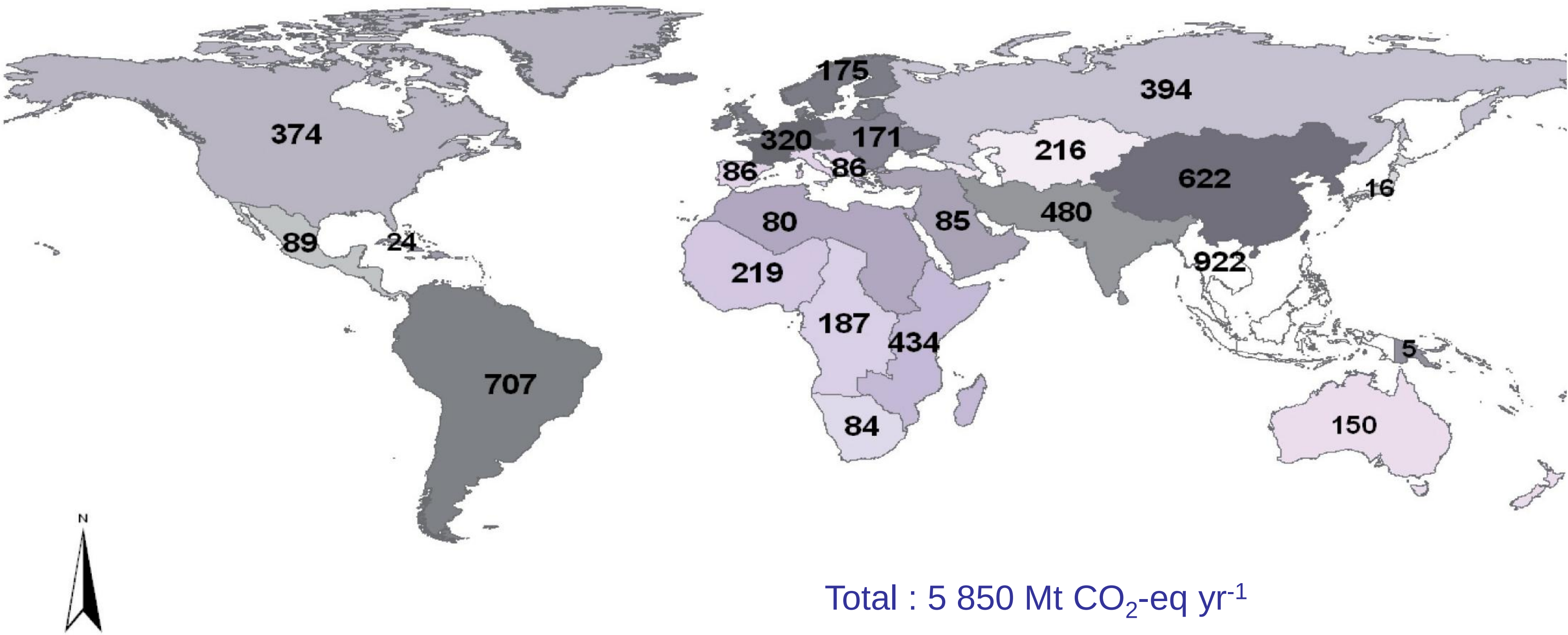
Carbon sequestration in agricultural soils : 89 %

Mitigation of CH_4 emissions: 9 %

Mitigation of N_2O emissions: 2 %

(IPCC, 2007)

Mitigation potential of GHG emissions from the agriculture sector in 2030
(Mt CO_2 eq./year, B2 scenario, 100 $ US/tCO_2-eq)



Total : 5 850 Mt CO_2-eq yr^{-1}

IPCC 2007

70% of the mitigation potential is in developing countries

Drawn from data in Smith et al., 2007a.

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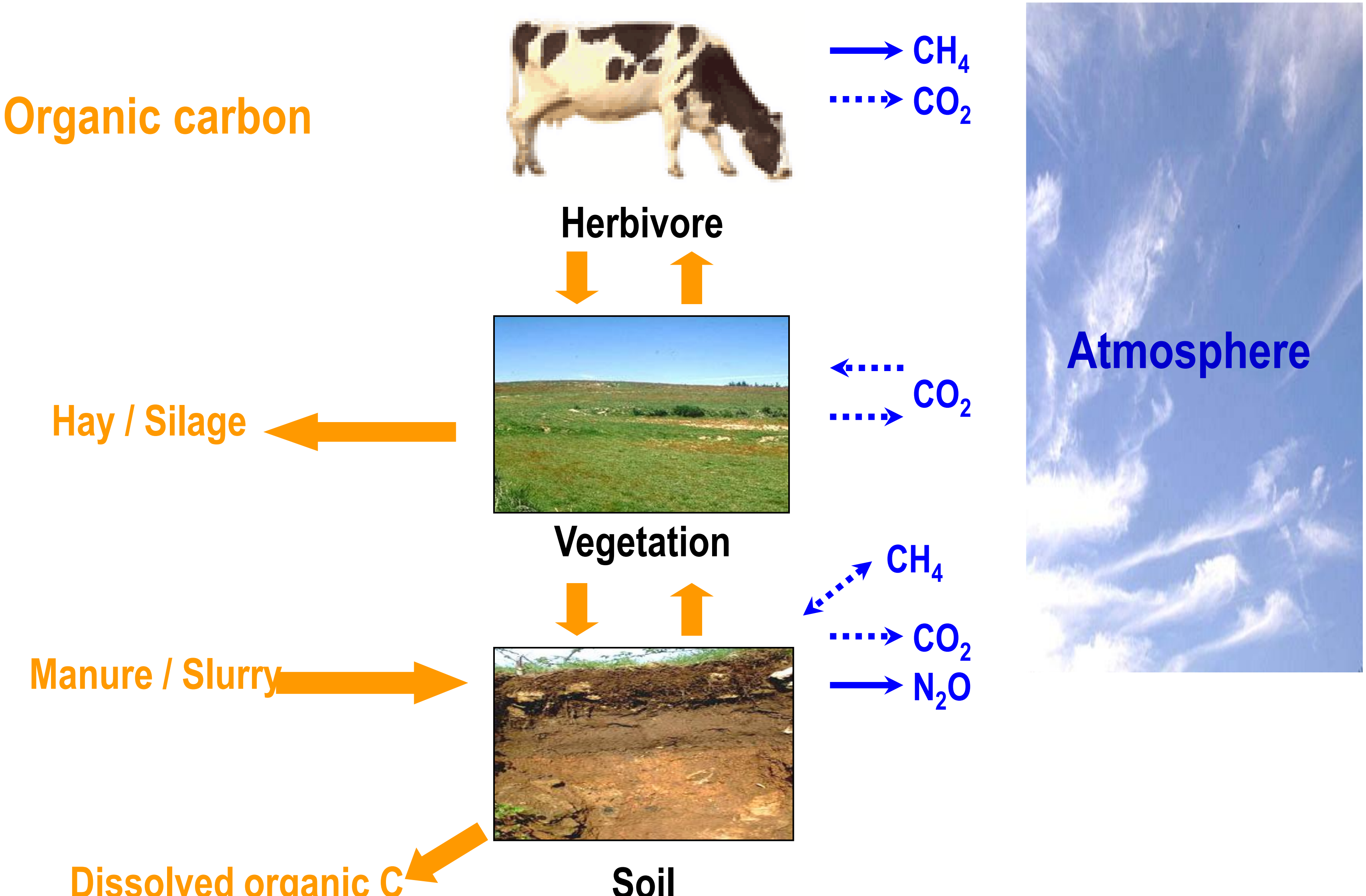
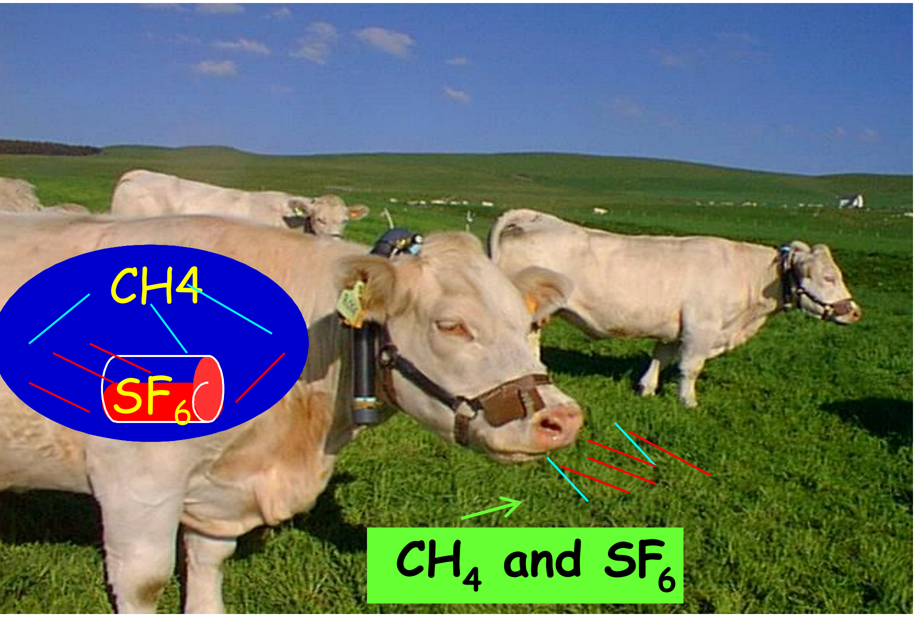
Greenhouse gas and organic carbon fluxes in a grassland



Greenhouse gas balance of 10 European grassland sites



CH_4 : *in-situ* dual tracer mehod

N_2O: automated chambers

On site emissions of N_2O and CH_4 , converted in CO_2 equivalents using the GWP of each gas, offset 43 % of the ecosystem C sink

The net greenhouse gas balance, also including off-site emissions of N_2O and CH_4 through digestion of cut herbage, is a small net sink by 85 ± 77 g C m^{-2} yr^{-1}

(Flechard et al., 2007, Pinares-Pineiro et al., 2007, Soussana et al., 2007)

Budgeting GHG: net GHG balance in CO_2 equivalents

In CO_2 equivalents, using the global warming potential (GWP) of each gas at the 100 years time horizon (IPCC, 2007):

NGHG : on site greenhouse gas balance

Attributed NGHG: on and off site greenhouse gas balance
Off site: emissions in the barn from cut herbage (digestion and wastes)

(Soussana and Tallec, 2009)

GHG balance in CO_2 equivalents at European sites

(g CO_2-C equivalents m^{-2} yr^{-1})

Management	NCS	Att-NCS	NGHG	Att-NGHG
Grazing	471	471	320	320
Grazing & cutting	183	268	-22	-272
Cutting	259	359	230	-141

NGHG: grassland greenhouse gas balance

Att-NGH: attributed greenhouse gas balance (including off site emissions)

(Soussana et al., 2007, Soussana and Tallec, 2009)

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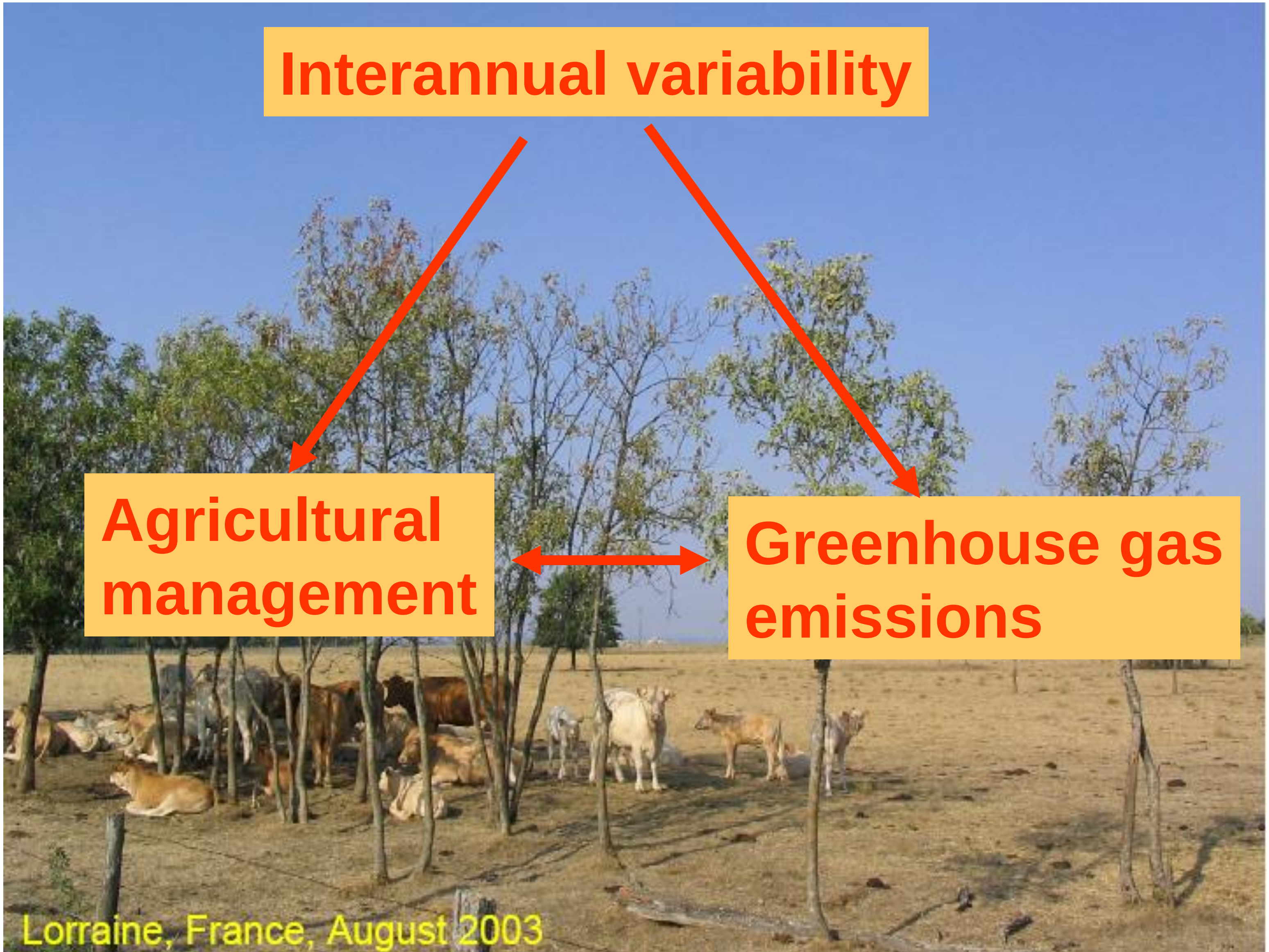
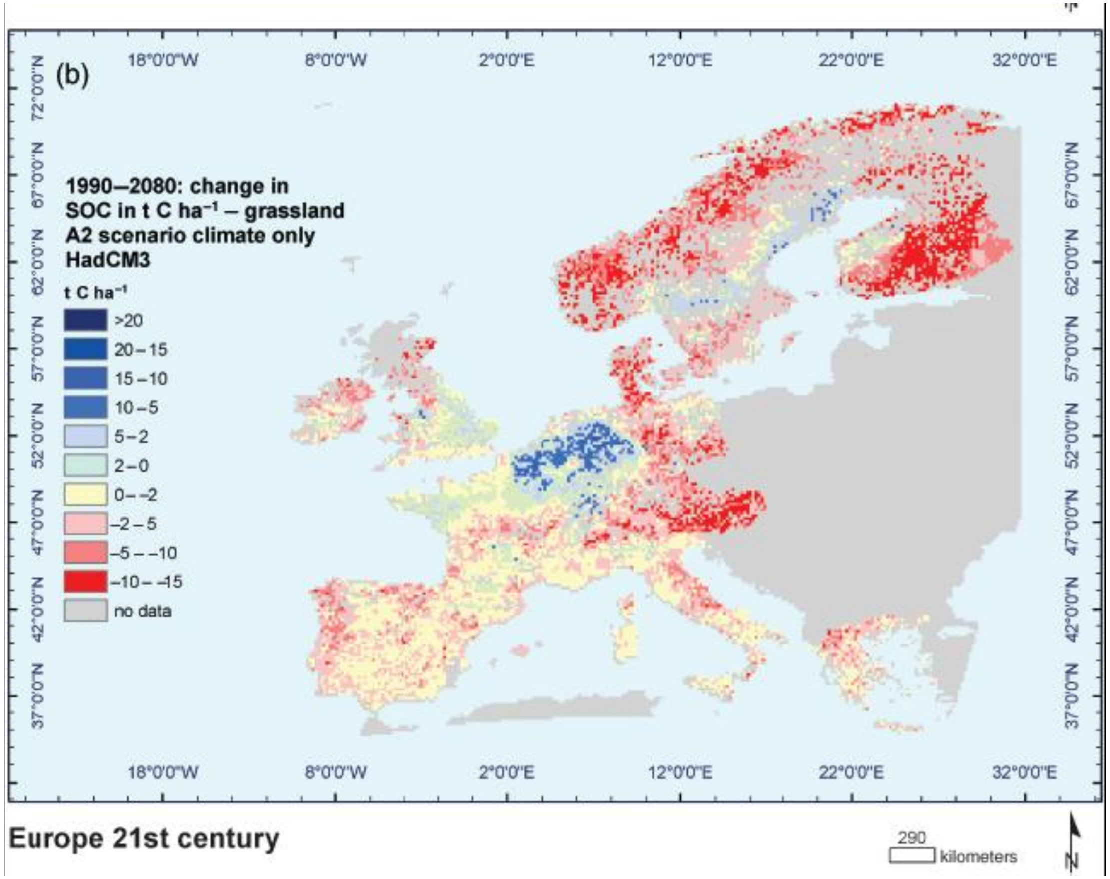
Impacts of climate variability and extremes on the C cycle in grasslands

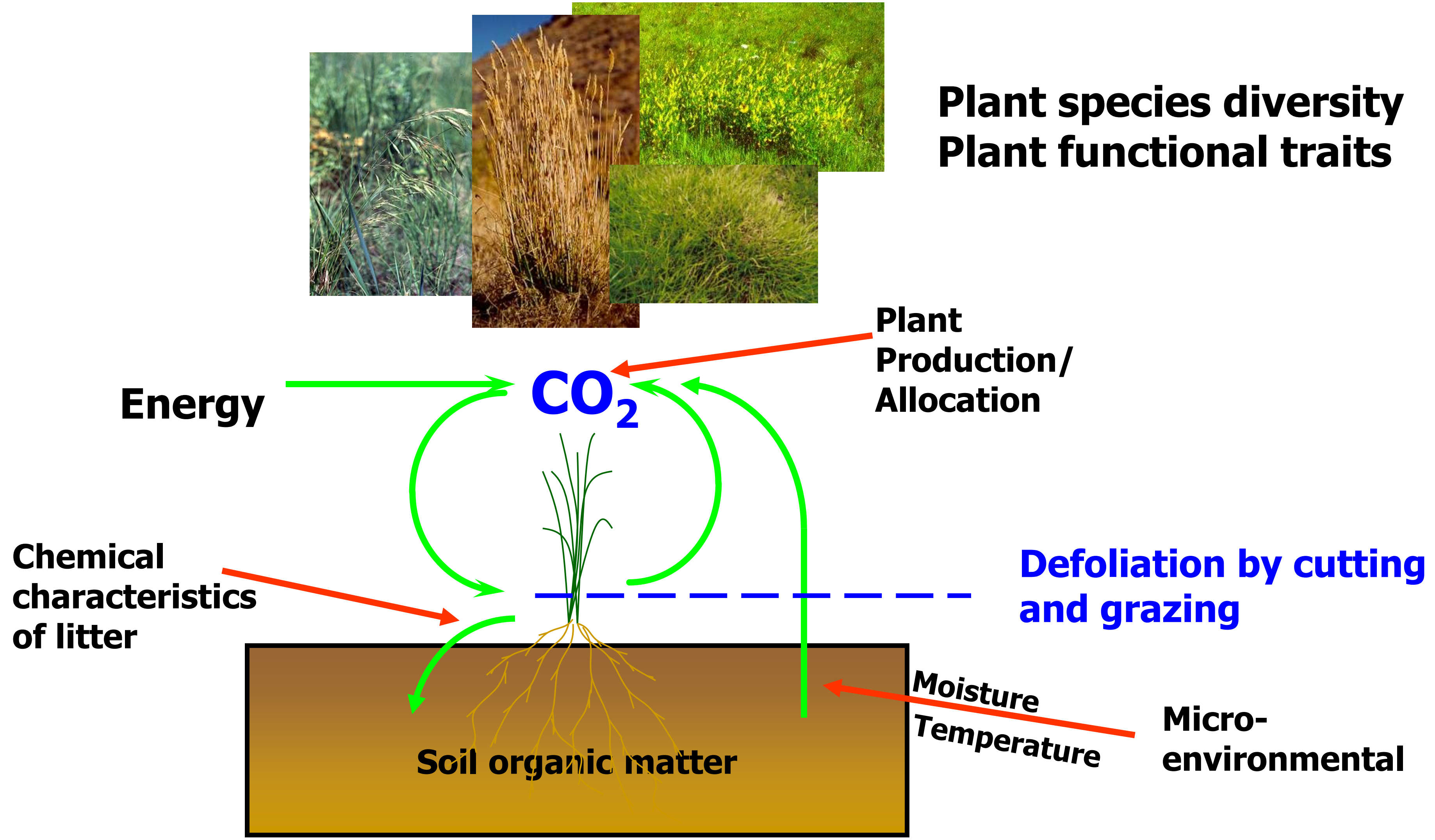


Climate change impact on grassland soil carbon sequestration

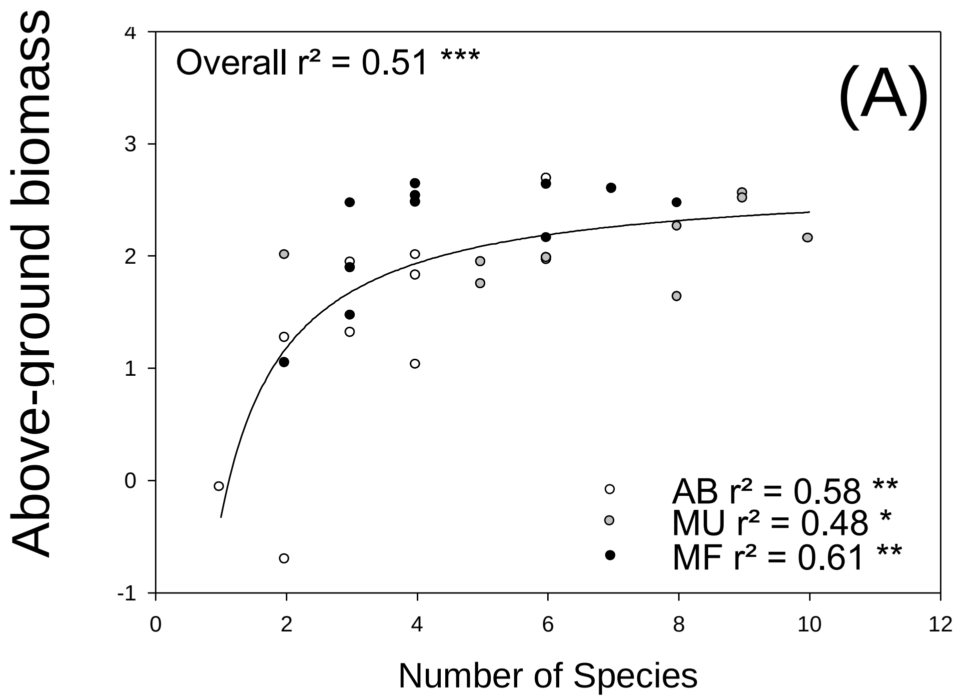


(Smith et al., 2005, Global Change Biol.)

Biodiversity loss may impact C sequestration



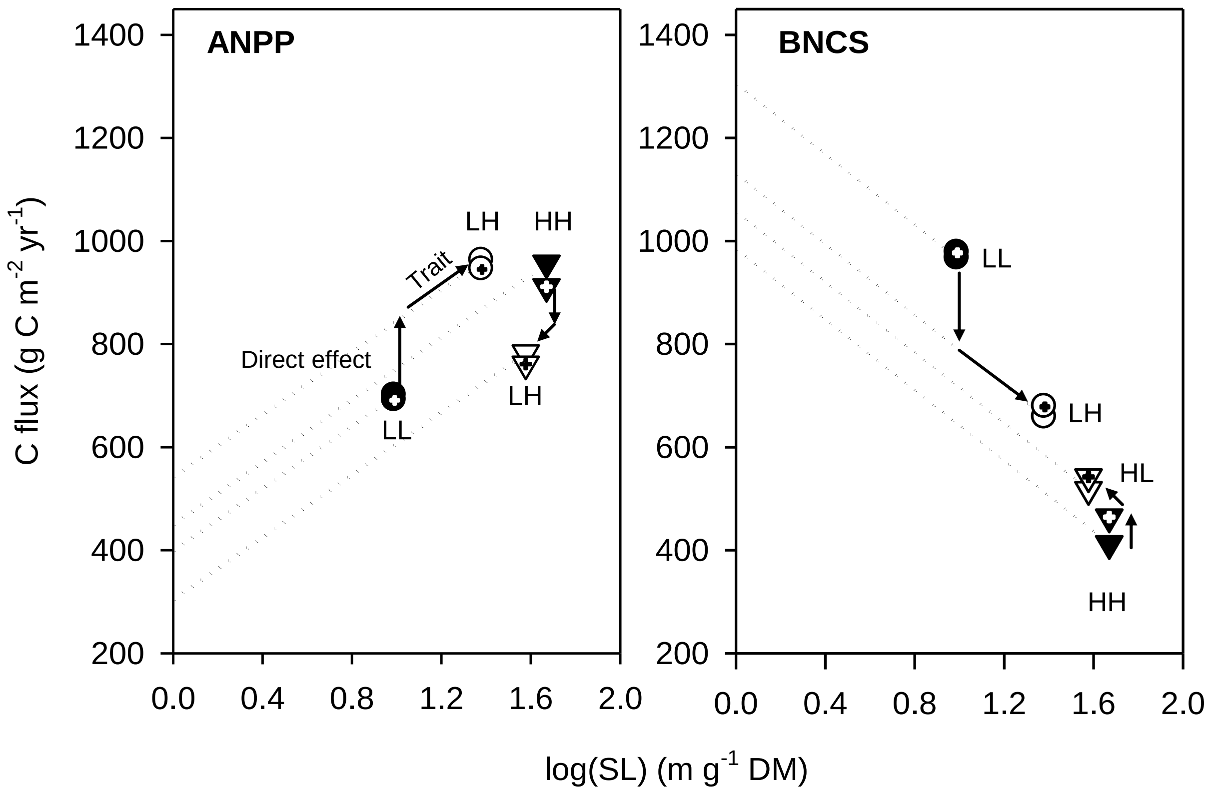
Biodiversity effect at patch scale in managed grasslands



The more plant species in a permanent grassland patch, the higher the local productivity

(Gross et al., in revision, BAE)

Root traits effects on productivity and C sequestration



C sequestration declines when there are less coarse roots

(Klumpp and Soussana, 2009 Global Change Biol., in press)

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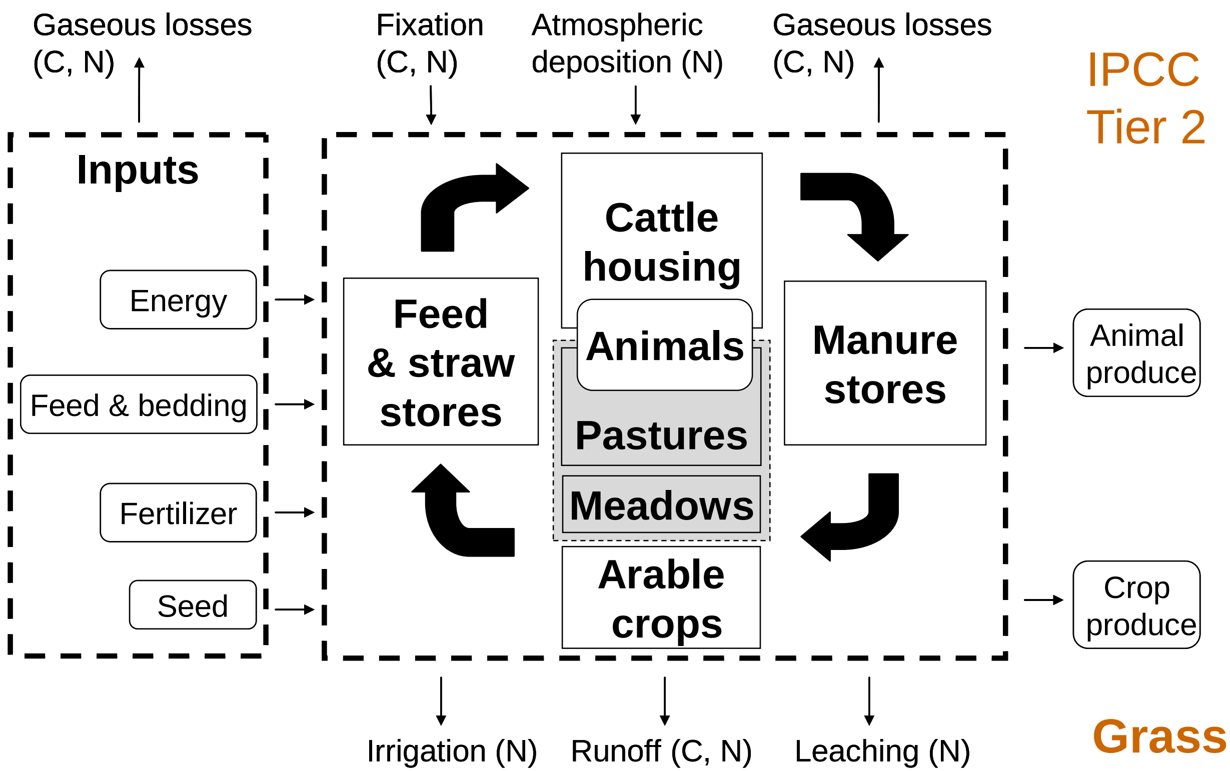
A model of GHG and C sequestration in livestock farms (FARMSIM)

Lifecycle analysis

IPCC Tier 2

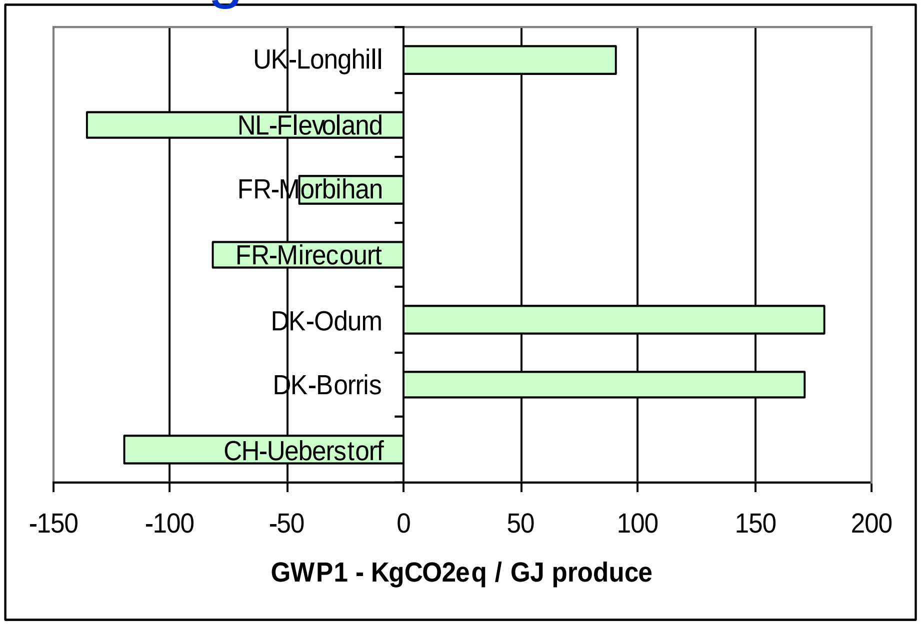


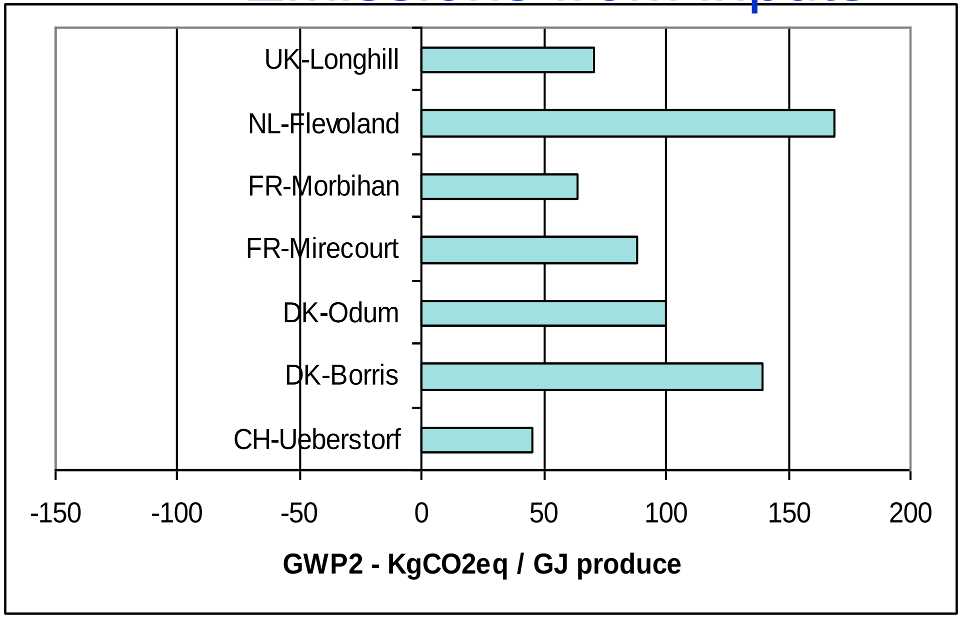
Grassland and crop models

A dynamic model coupling lifecycle analysis and carbon sequestration
(Salettes et al., 2004; Schils et al., 2007; Duretz et al., 2009)

Net greenhouse gas balance of cattle farms per unit energy in animal products (FarmSim model)

Farm-gate fluxes + Emissions from inputs



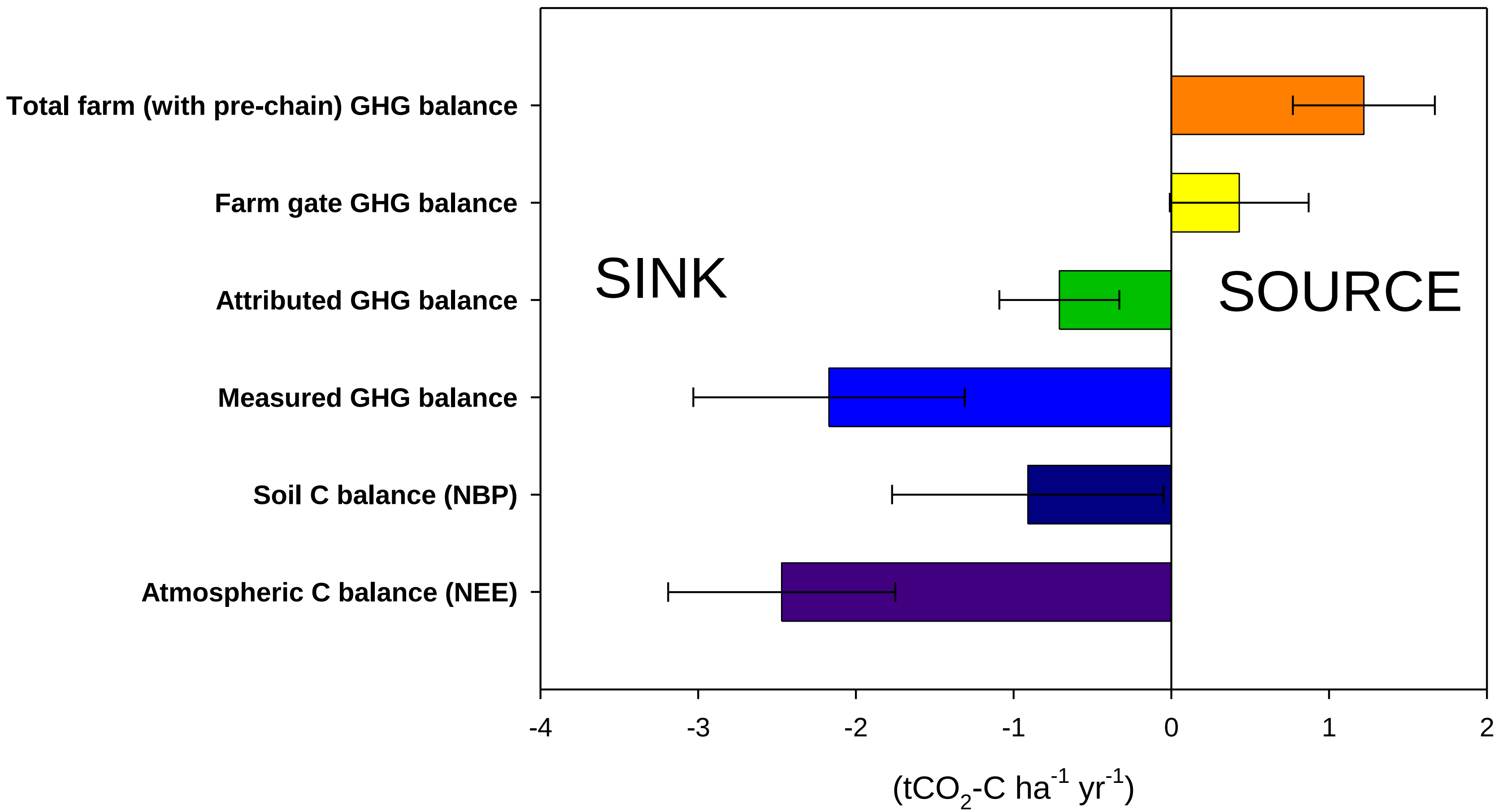


There are large between farm variations in greenhouse gas balance

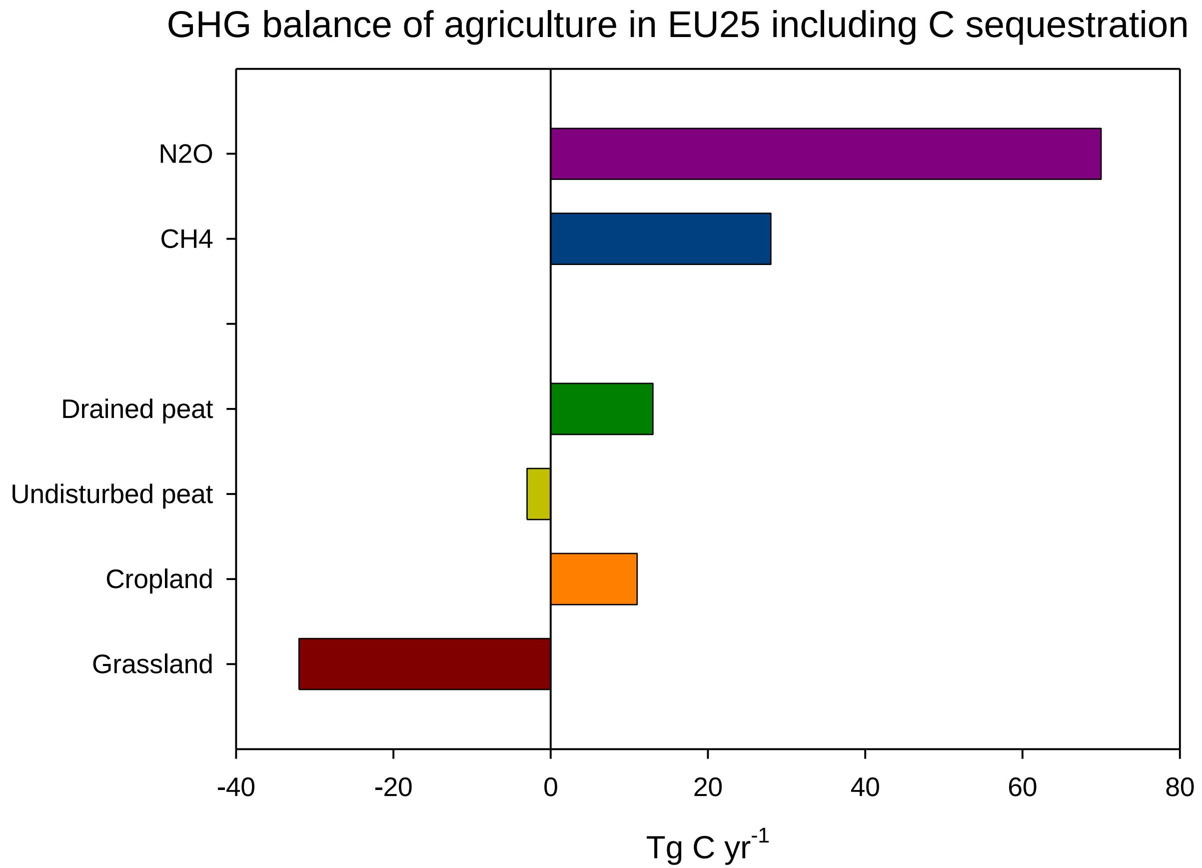
GHG emissions are positively correlated with a farm gate surplus of N

(Schils et al., 2007, Fiorelli et al., 2008)

Summary: greenhouse gas balance per unit area of grasslands and of livestock farms



The GHG balance of the agriculture sector in Europe



Grassland C sequestration would play a significant role for the European agriculture sector

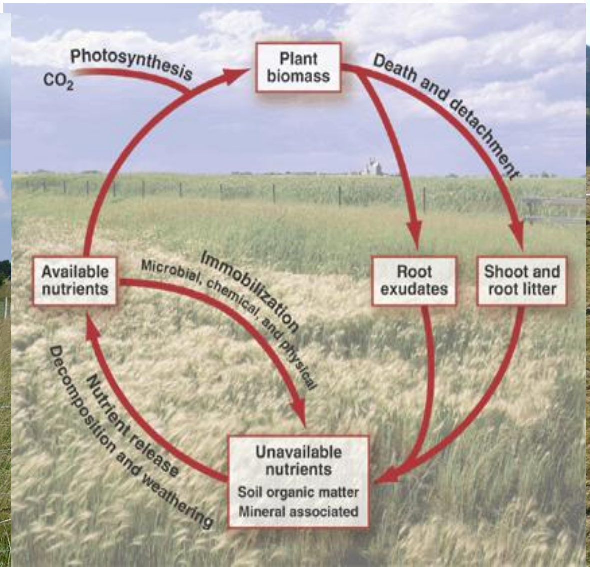
(Schulze et al., submitted to Nature Geosciences)

Concluding remarks

- There is a clear potential for C sequestration in European grasslands
- An internationally agreed methodology is still missing to develop mitigation options in the livestock sector based on C sequestration
- Reducing CH_4 and N_2O emissions from the livestock sector is strongly needed, given that soil carbon sequestration is reversible and vulnerable to climate change and biodiversity loss
- Mitigation strategies could be based on the net GHG balance of livestock farms



Thank you



Photosynthesis
CO_2
Plant biomass
Death and detachment
Available nutrients
Immobilization
Microbial, chemical, and physical
Root exudates
Shoot and root litter
Nutrient release
Decomposition and weathering
Unavailable nutrients
Soil organic matter
Mineral associated