Impact of soil and crop management on carbon sequestration in soils

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Outlines

Introduction

Soil organic carbon sequestration (SOC)

Land use change

Nutrient Management and SOC sequestration

Tillage and SOC sequestration

Water Management and SOC sequestration

Potential of C sequestration

SOC , Soil Health and Food Productivity

Soil Organic Carbon Sequestration

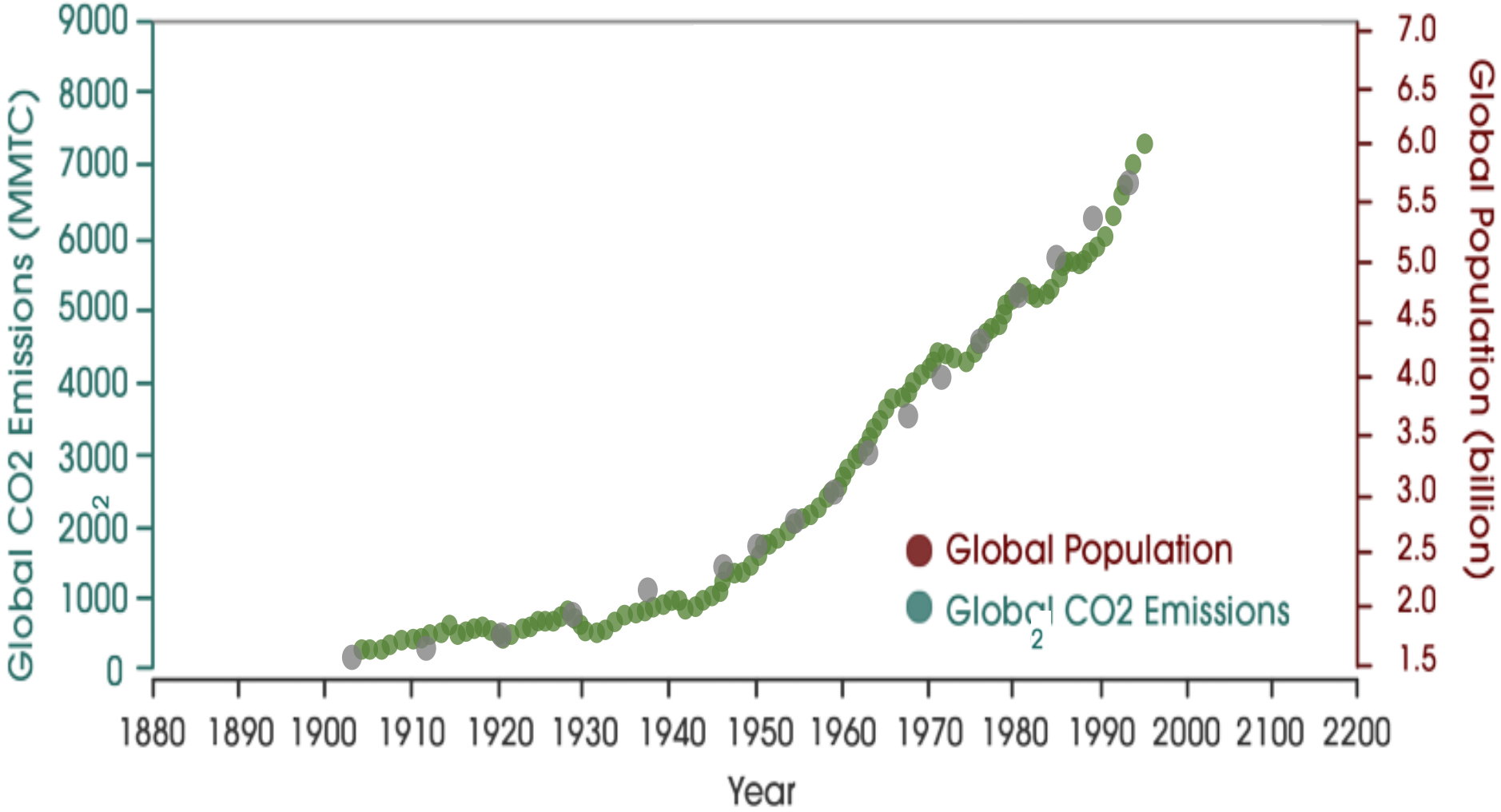
It is the process of transferring CO_2 from the atmosphere **into the soil of a land unit, plants,** plant residues, and other organic solids which are ***stored or retained in the unit as a part of the soil organic matter* with a long mean residence time.**

Olson, Al-Kaisi, Lal, Lower (2014)

Soil carbon Sequestration (cont.)

- **Over the past 200 years, the CO_2 emissions have lead to ever-increasing concentration of CO_2 in the atmosphre (from 280 ppm in 1750 to 407 ppm in 2017)**
- **This is the highest concentration in the past 800 000 yrs.**
- **The increase has been caused by human activities, particularly by burning of fossil fuel, deforestation and land use changes.**

Global Population vs. Global CO_2 Emissions



World Climate Report, 2008

http://bloomtrigger.com/en/Home/Pages/global-co2-emissions

Expansion of Global Agricultural Land

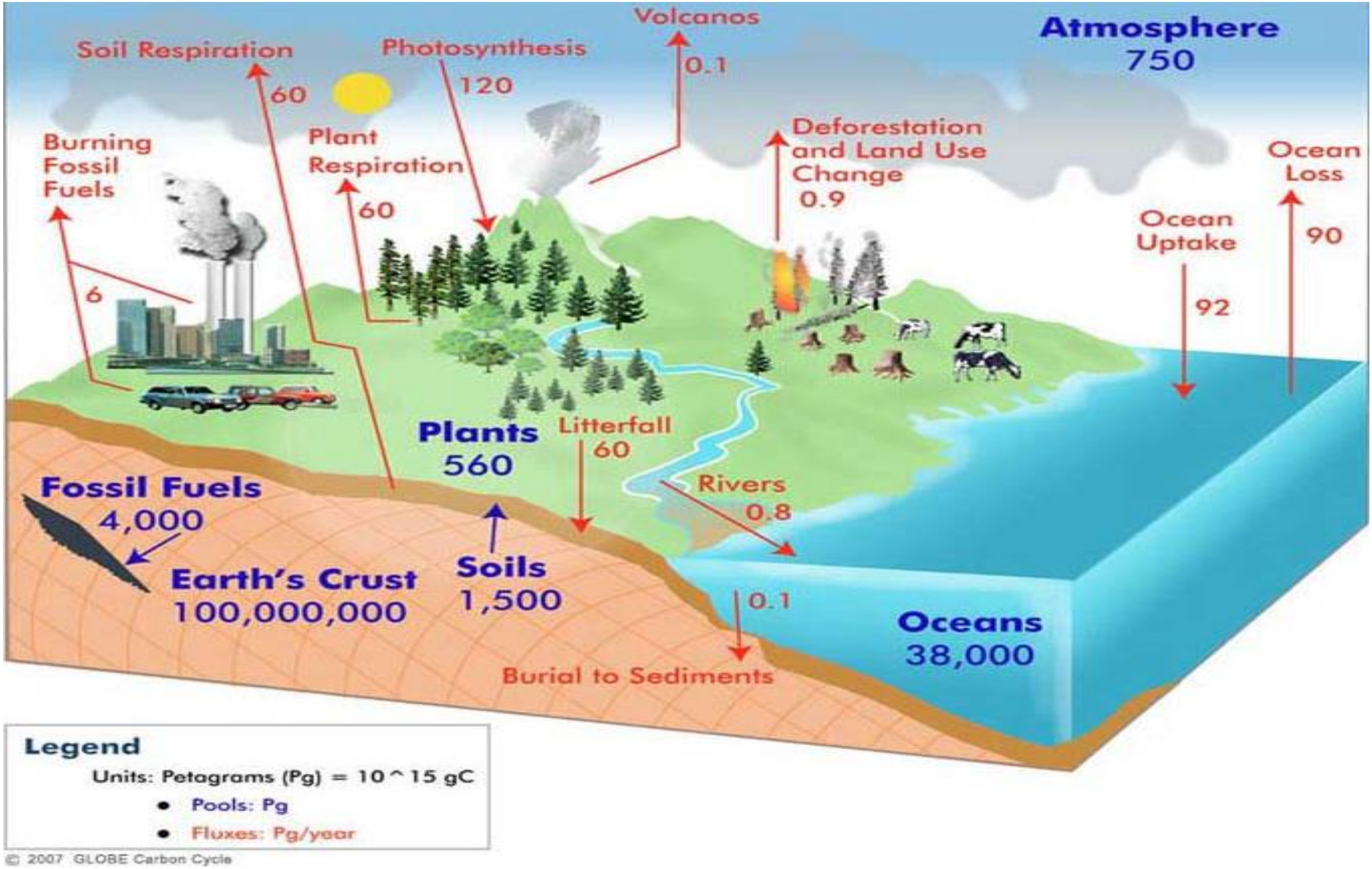
Year	Population (10^6)	Agricultural Land (10^6 ha)		
		Cropland	Pasture land	Irrigated
1	188	130	110	-
1800	989	420	510	8
2000	6896	1381	3357	280
2017	7550	1417	3314	331

Lal (2019) Seminar at NMBU

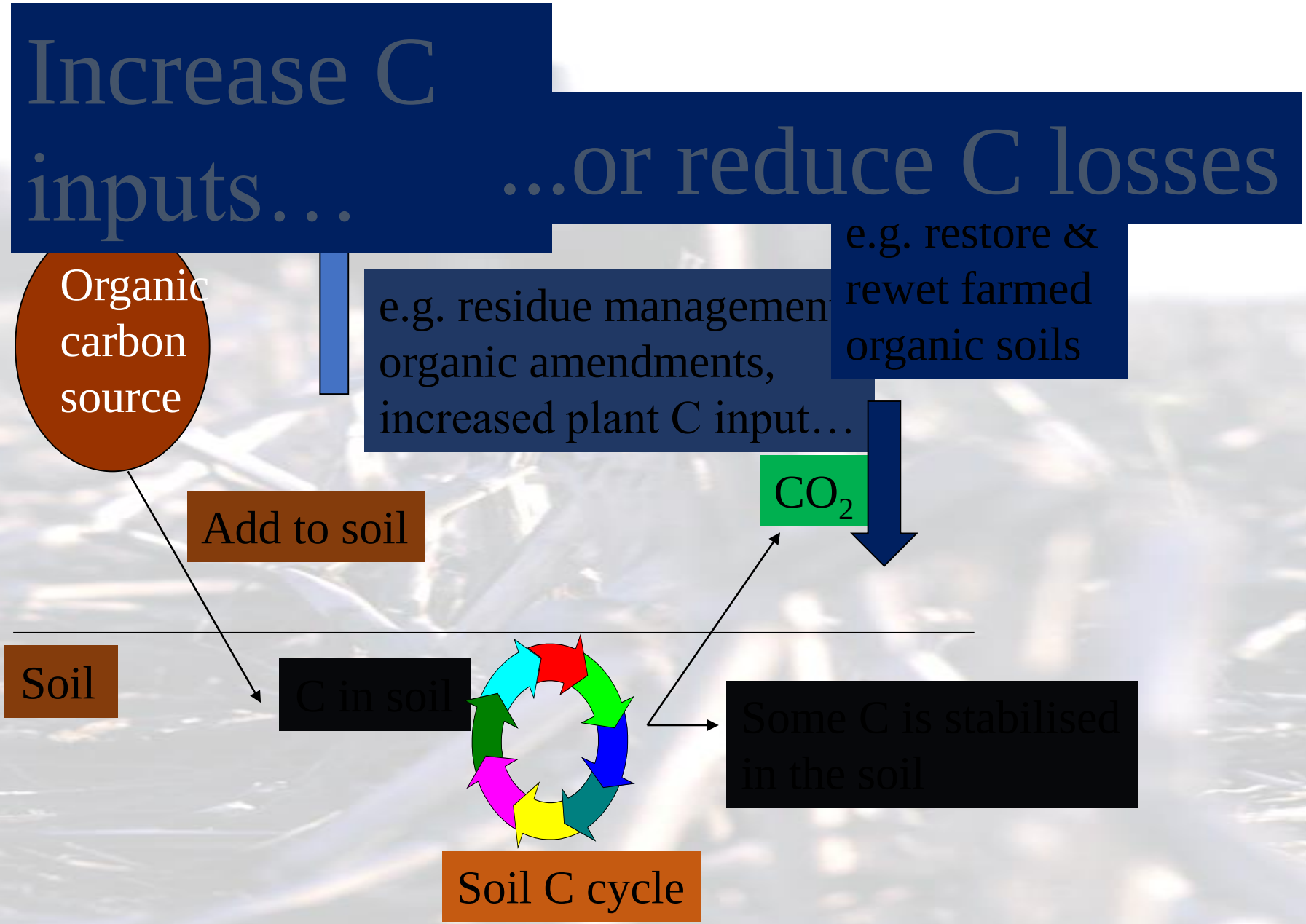
- **Processes and practices leading to emission include deforestation, biomass burning, soil cultivation conversion of natural lands to agriculture, drainage of peat lands while biomass burning and cultivation making major contribution to this emission.**

- **Among the active pools of carbon, soil has the highest pool, but there are dynamic changes in C among various pools caused by natural and anthropogenic processes .**

Key carbon cycling dynamics and its global magnitudes in terrestrial ecosystems



How does soil C sequestration work?



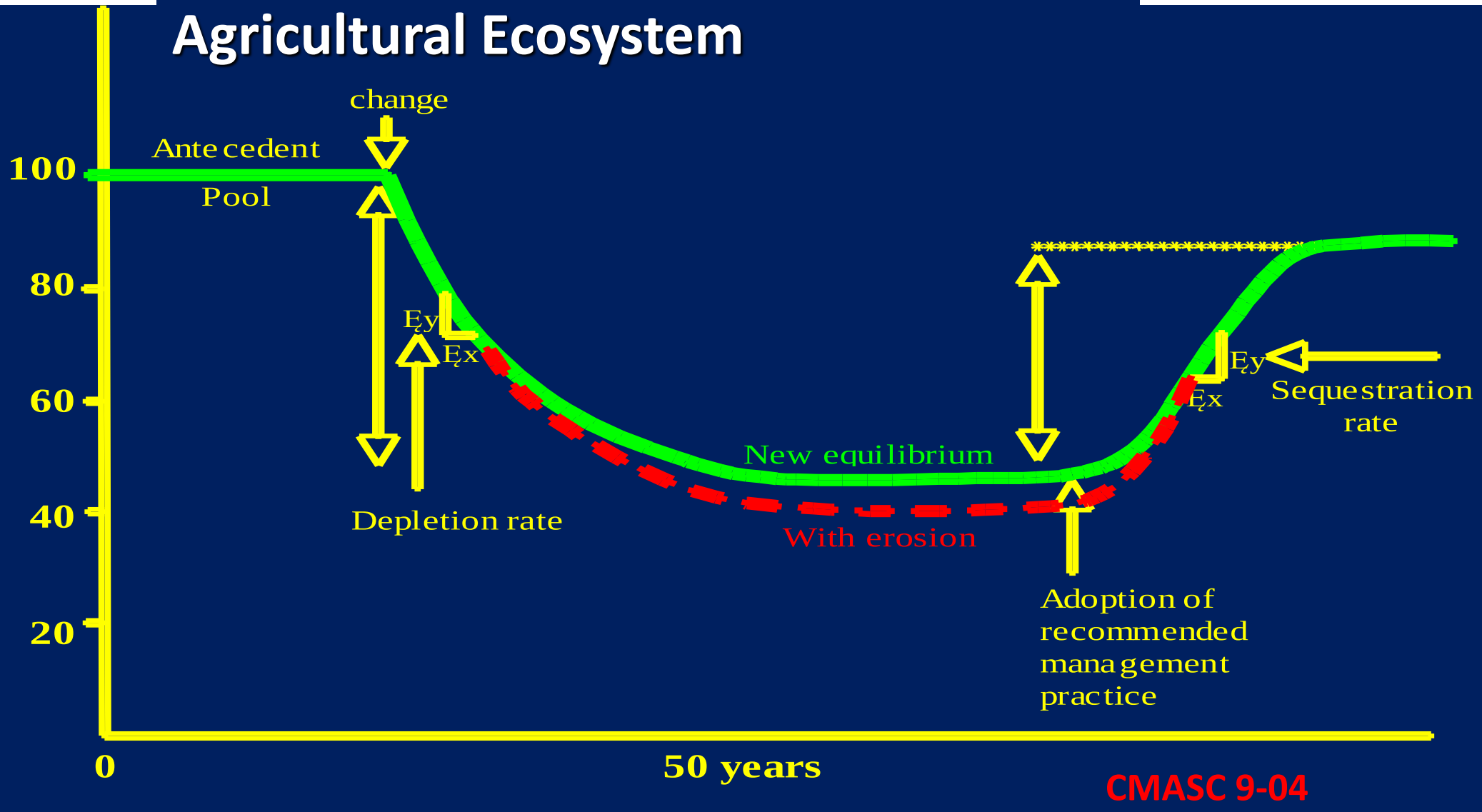
Smith (2006)

Causes for soil carbon loss to atmosphere

Carbon loss from cultivated peat soils in Norway

Land use change and SOC

SOC Depletion by Land Use Conversion From Natural to Agricultural Ecosystem



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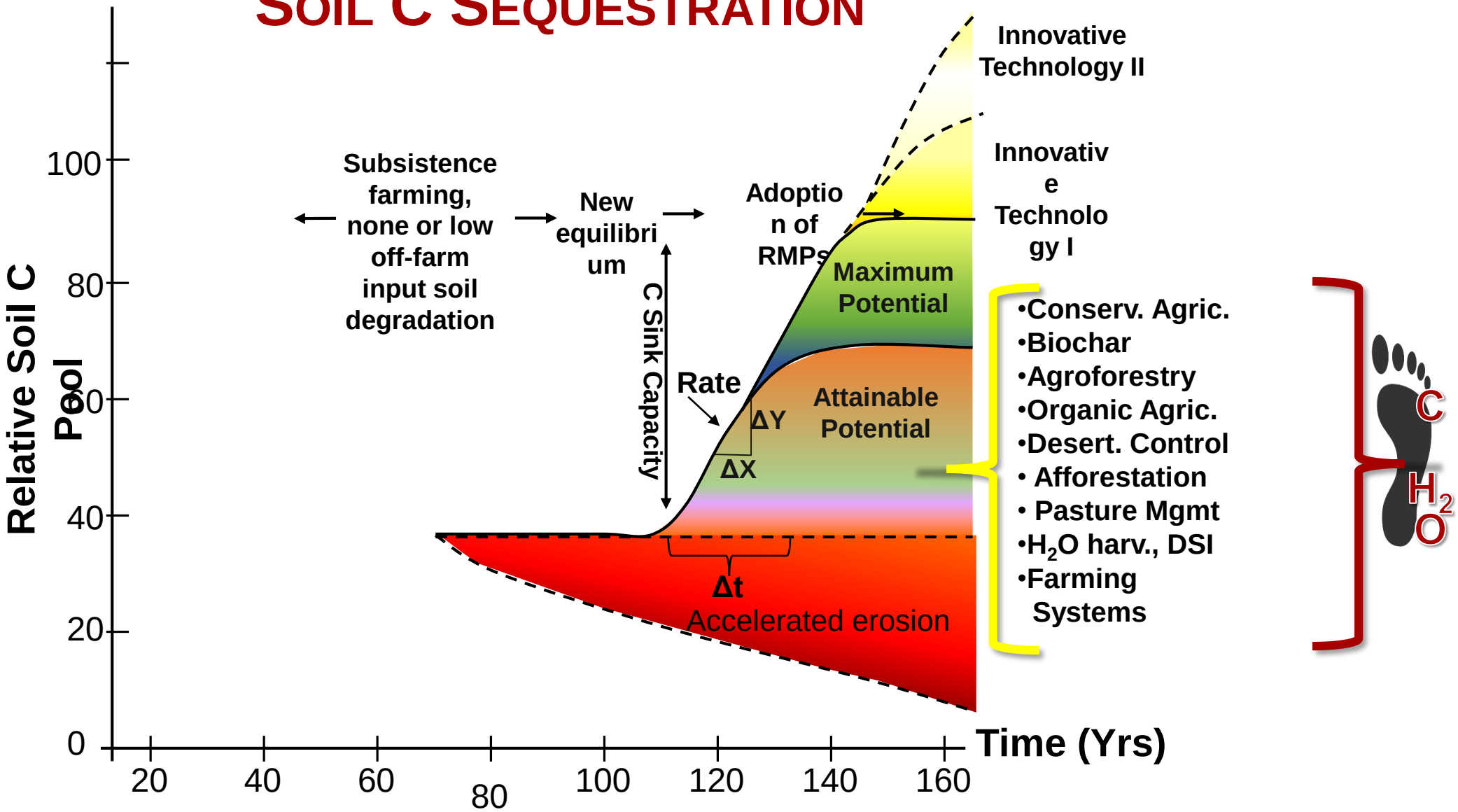
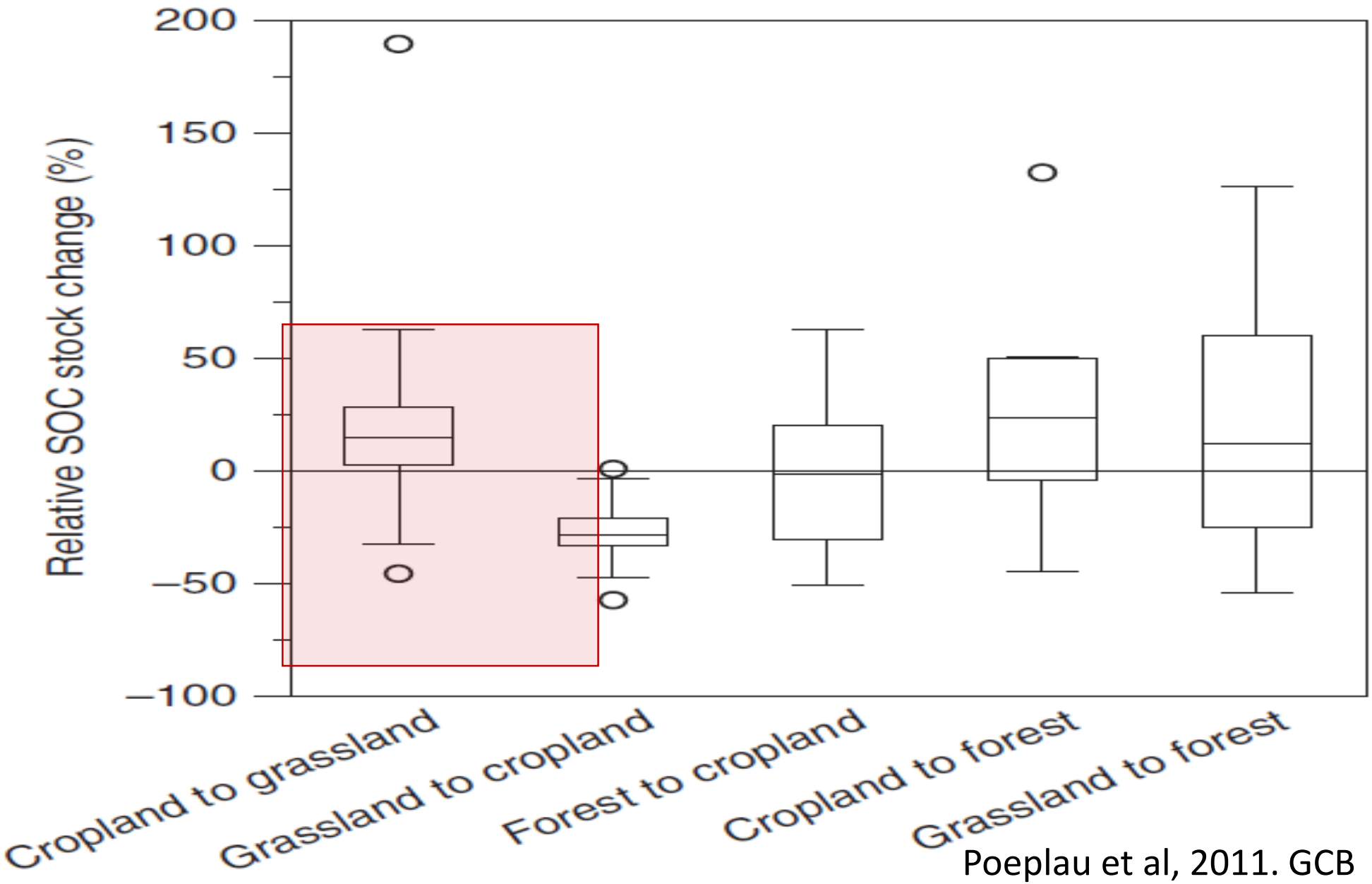
SOIL C SEQUESTRATION



In most cases, the maximum potential equals the magnitude of historic C loss. Only in some soil-specific situation, the adoption of RMPs can increase SOC pool above that of the natural system. An example of this is acid savanna soils of South America (Llanos, Cerrados) where alleviation of soil -related constraints can drastically enhance the SOC pool. Lal, 2004

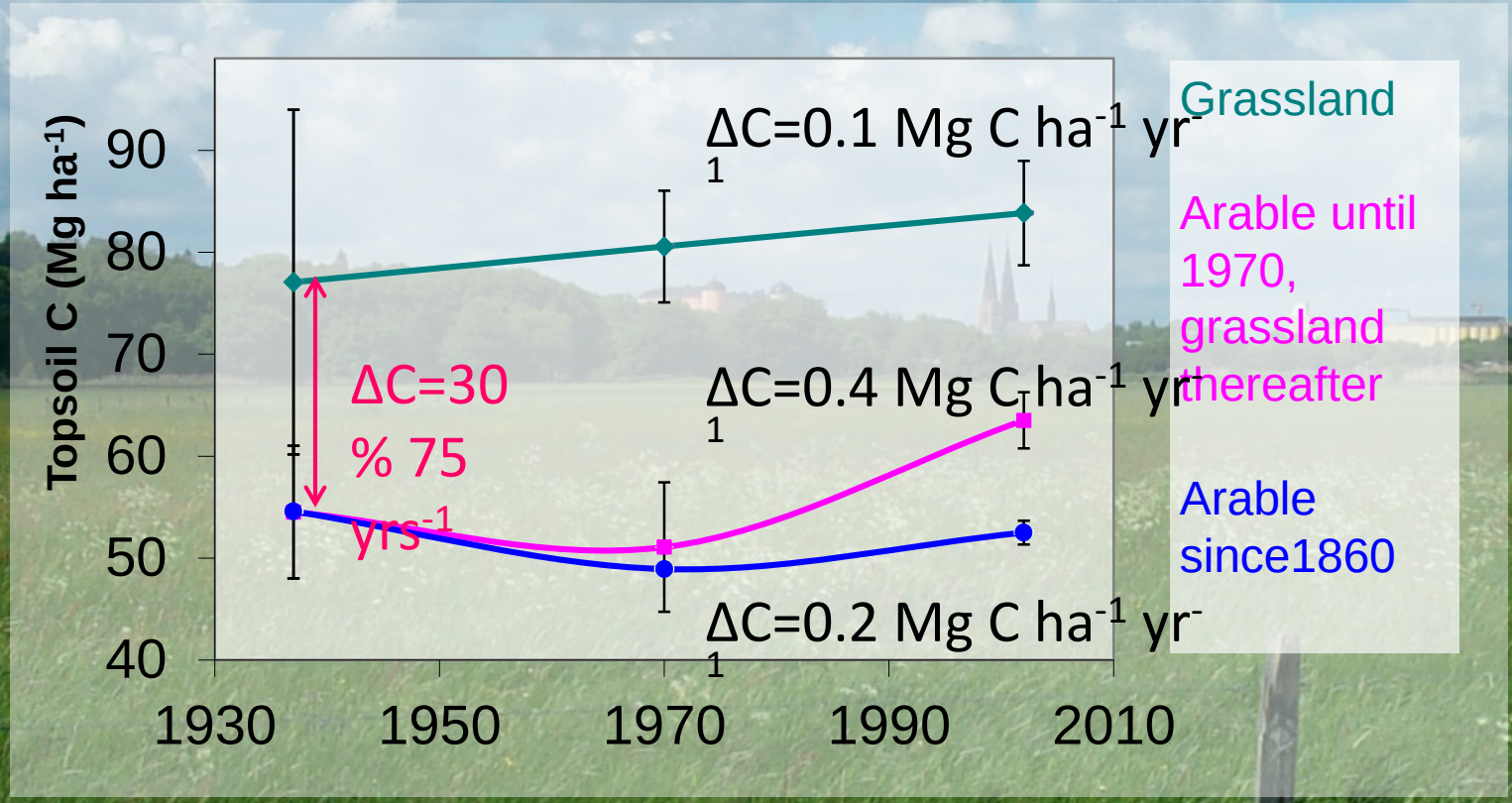
Land use change and soil C change in temperate climates



Poeplau et al, 2011. GCB

Case study: Land use change - effects on soil C

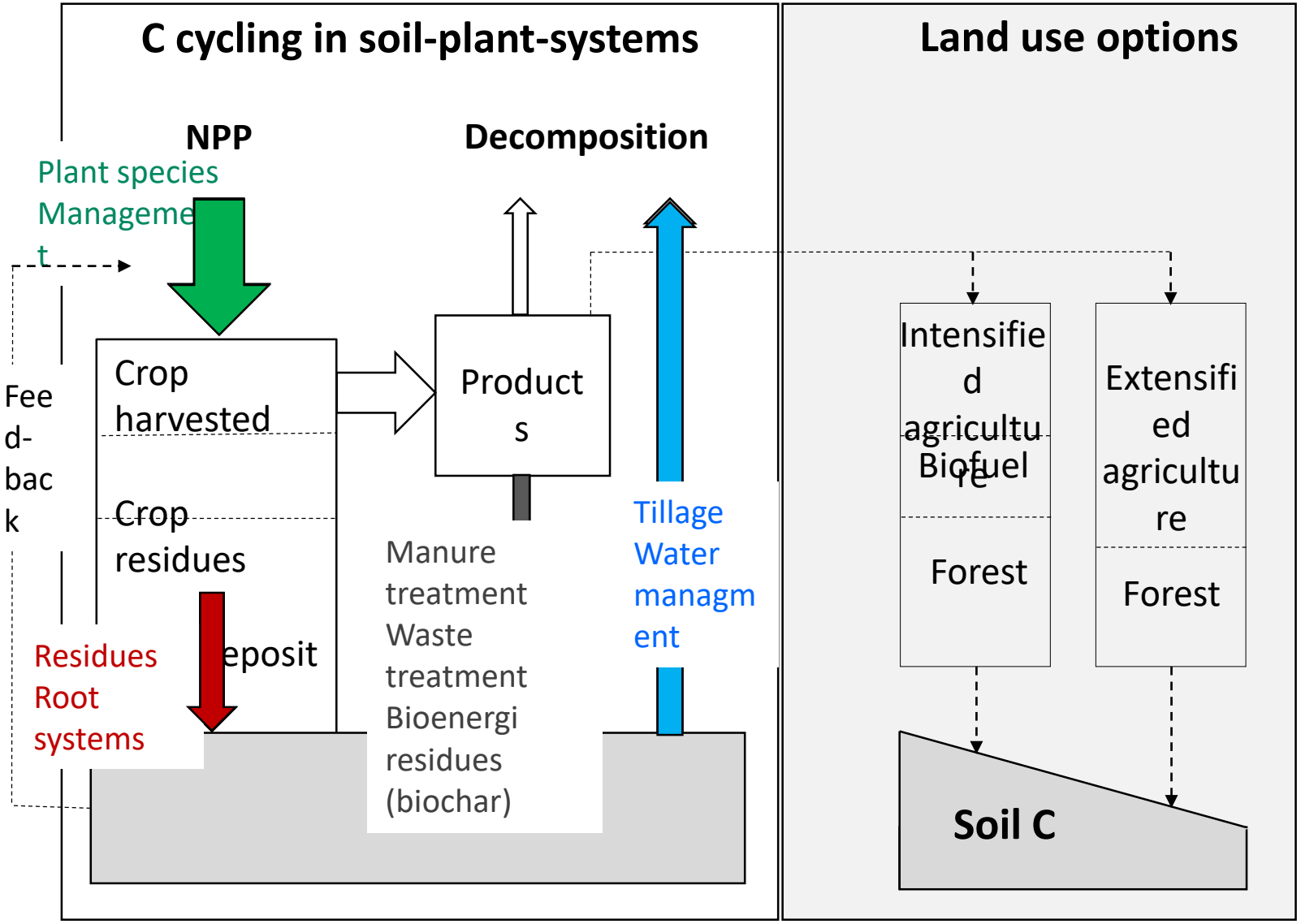
3 adjacent fields, Kungsängen, Sweden



Kätterer et al. 2008. Nutr. Cycl. Agroecosys. 81:145–155

Nutrient Management and SOC

Carbon cycling in agricultural systems is driven by management decisions



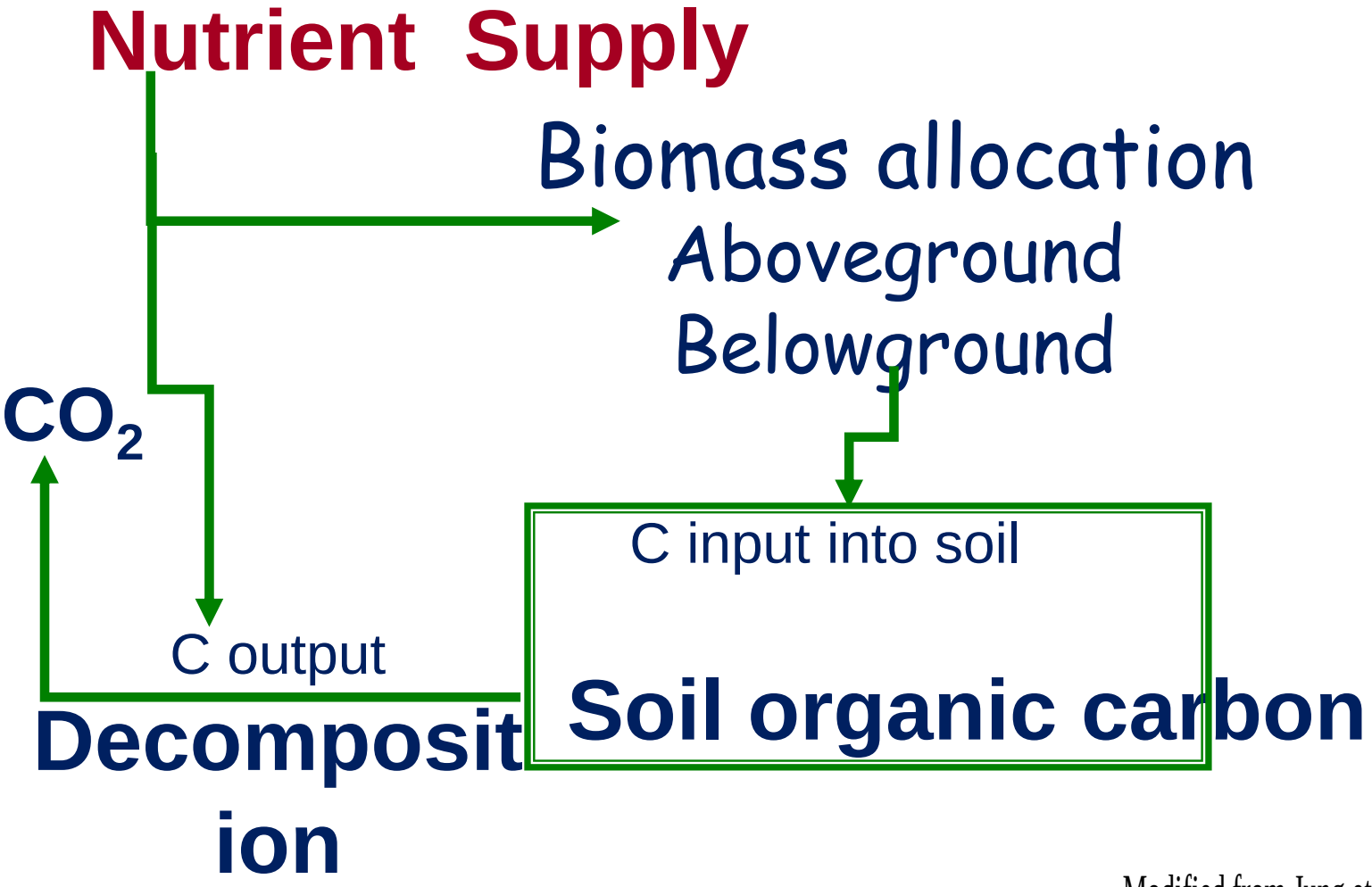
Kätterer et al., 2012. Acta Agric. Scand.

Soil carbon Sequestration (cont.)

- **A promising way to reduce the atmospheric CO_2 is to encourage management policies promoting plant growth which leads to C sequestration in vegetation and in soils.**

- **However, the potential of this sink to mitigate CO2 emissions, may be constrained by nutrients and water supply.**

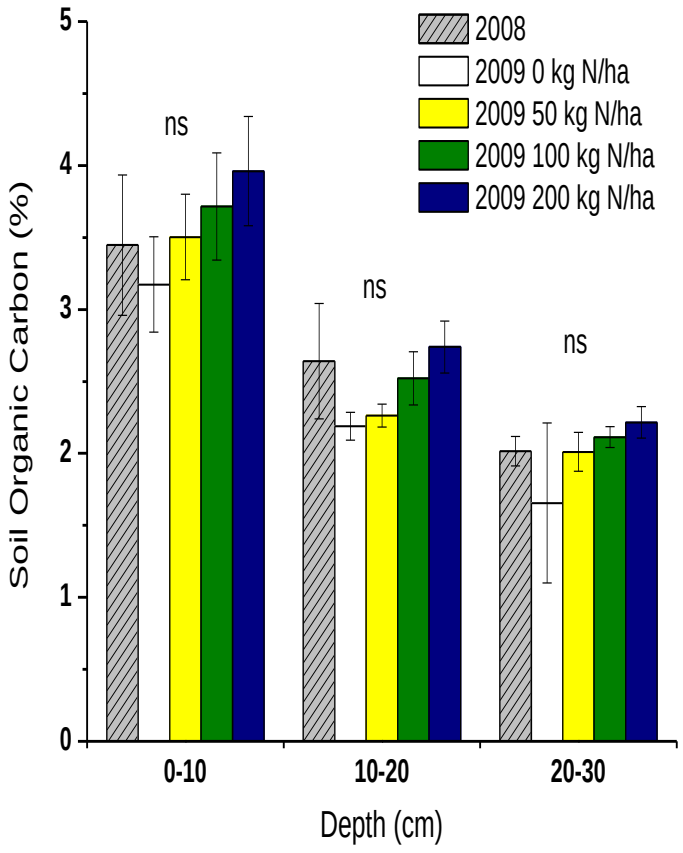
Modus Oprendai



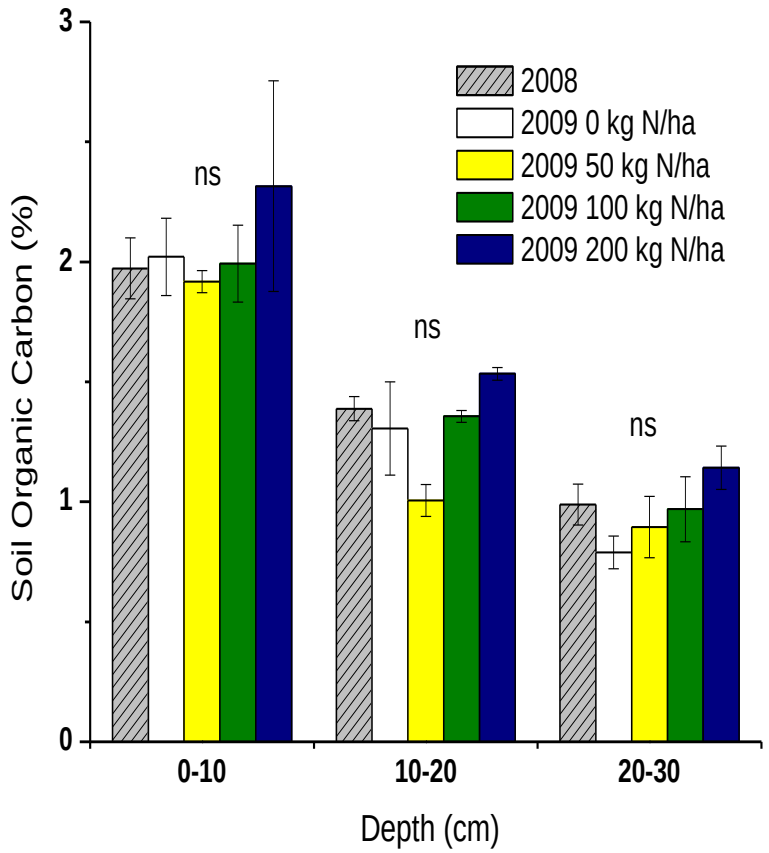
Modified from Jung et al (2011)

SOC with N Application

Hoytville

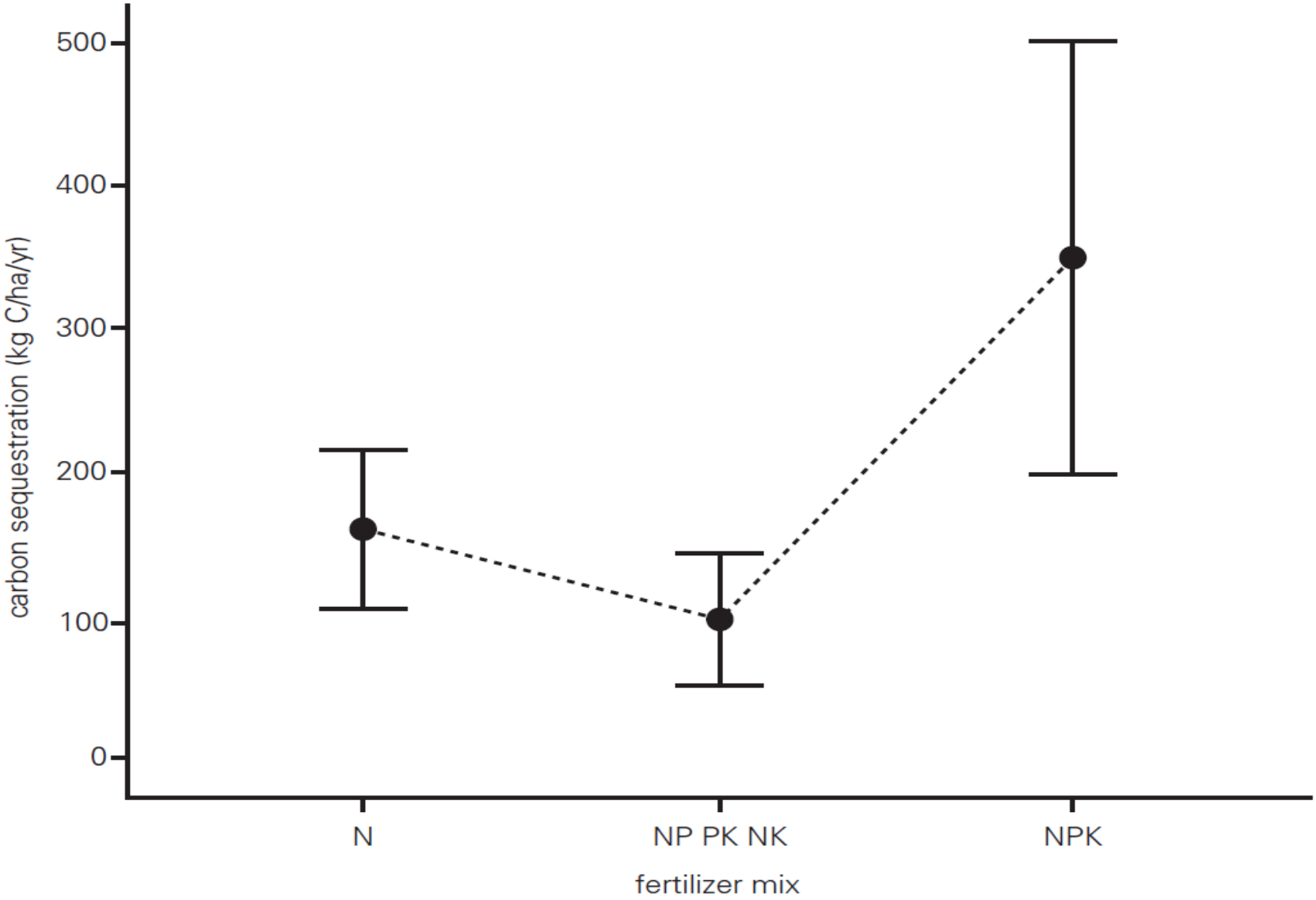


Jackson



Jung et al. (2011)

FIGURE 3.7: Soil Carbon Sequestration and Fertilizer Combinations (Means and 95 Percent Confidence Intervals, $n = 285$)



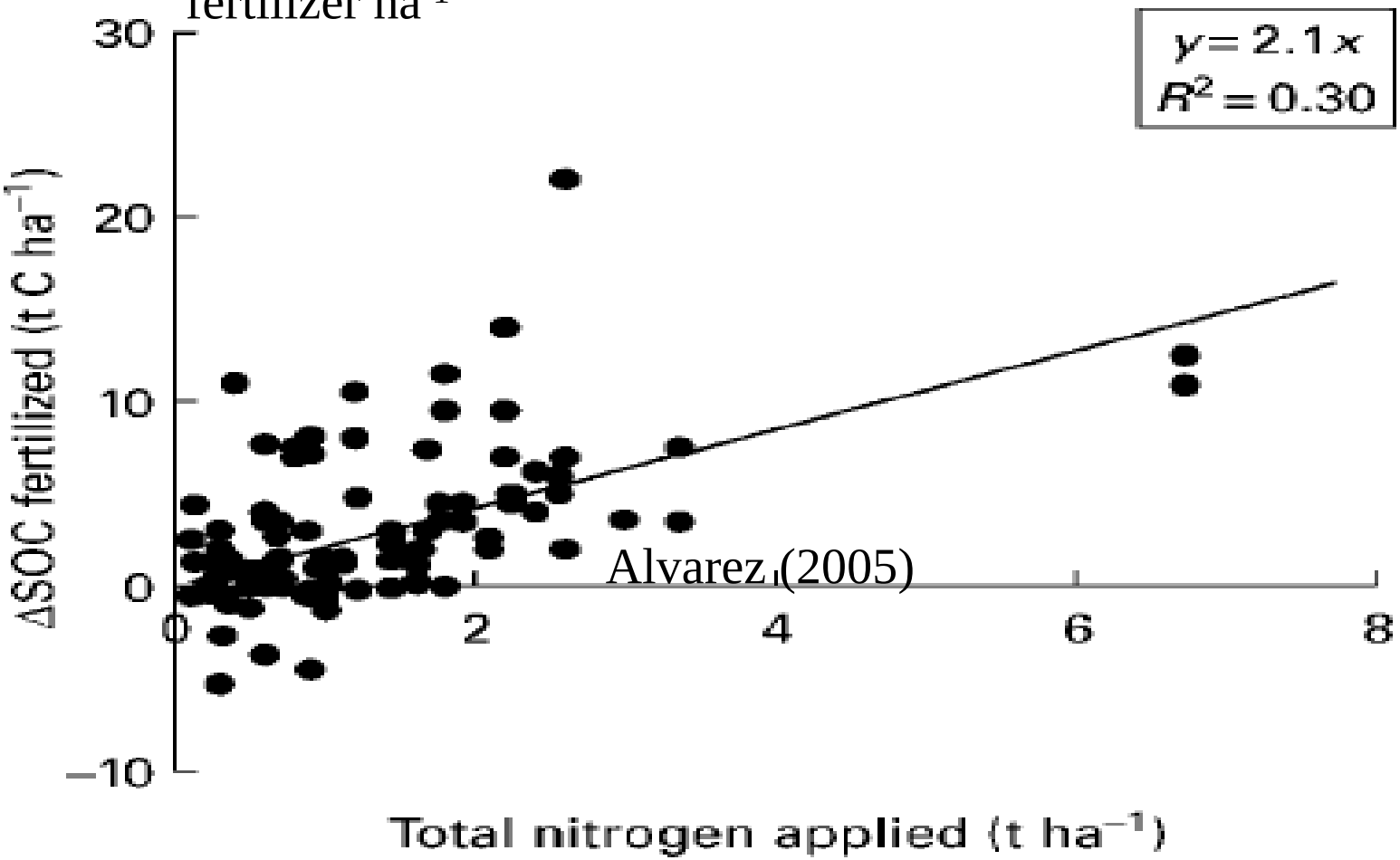
Source: The World Bank Report No.GLB(2012)

Nutrient management and SOC sequestration rate (kg C ha^{-1} yr^{-1})

Practice	Mean	Number of Estimate
Africa		
Chemical fertilizer	264	30
Manure	325	30
Asia		
Chemical fertilizer	222	297
Manure	465	146
Latin America		
Chemical fertilizer	124	74
Manure	455	25

Source: The World Bank Report No.GLB(2012)

About 2 Mg C ha^{-1} for each 1 Mg N fertilizer ha^{-1}



Alvarez (2005)

Figure 1. Relationship between carbon content differences of fertilized and control treatments (ΔSOC fertilized) and the total nitrogen applied in experiments with crop residues retained.

Alvarez (2005)

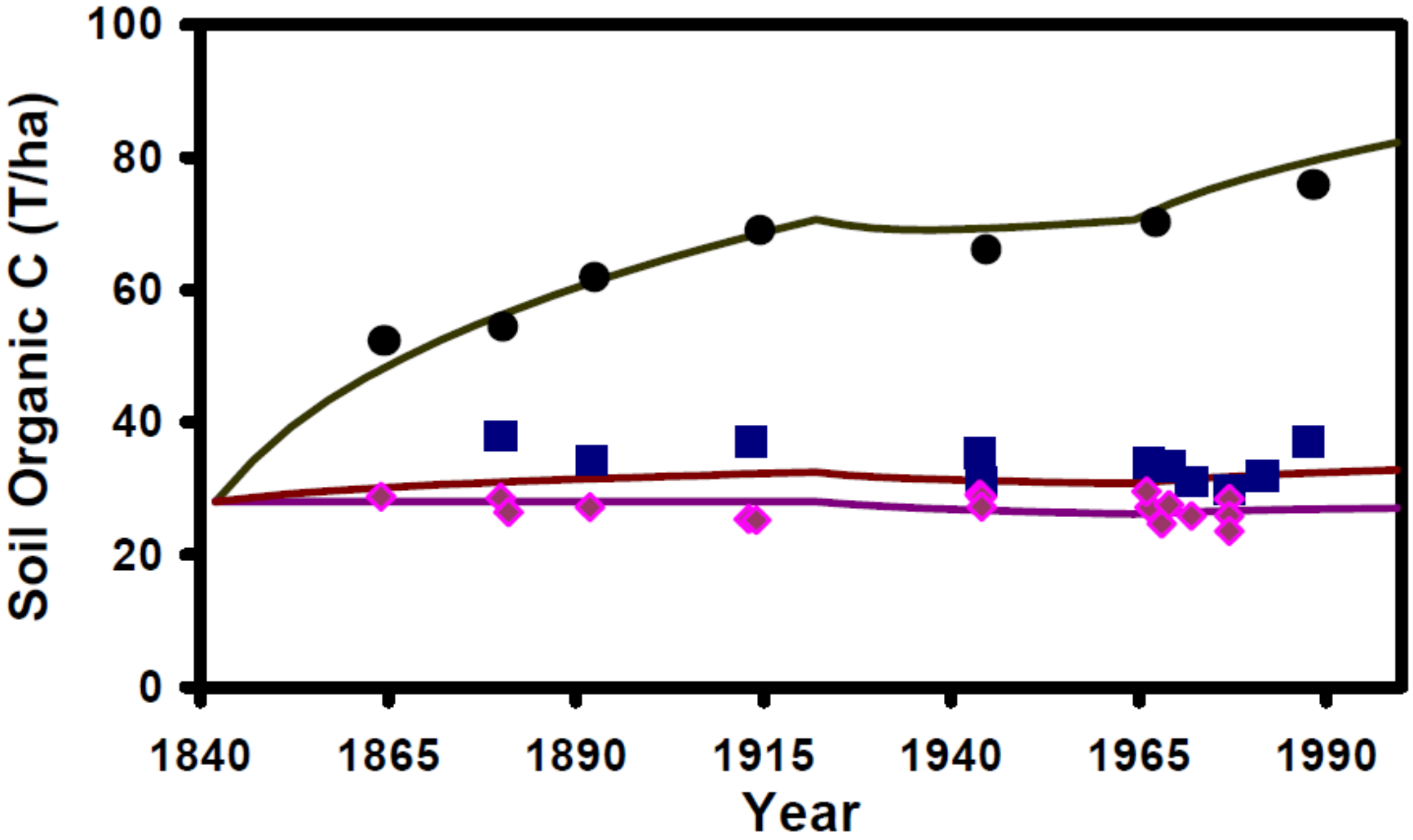
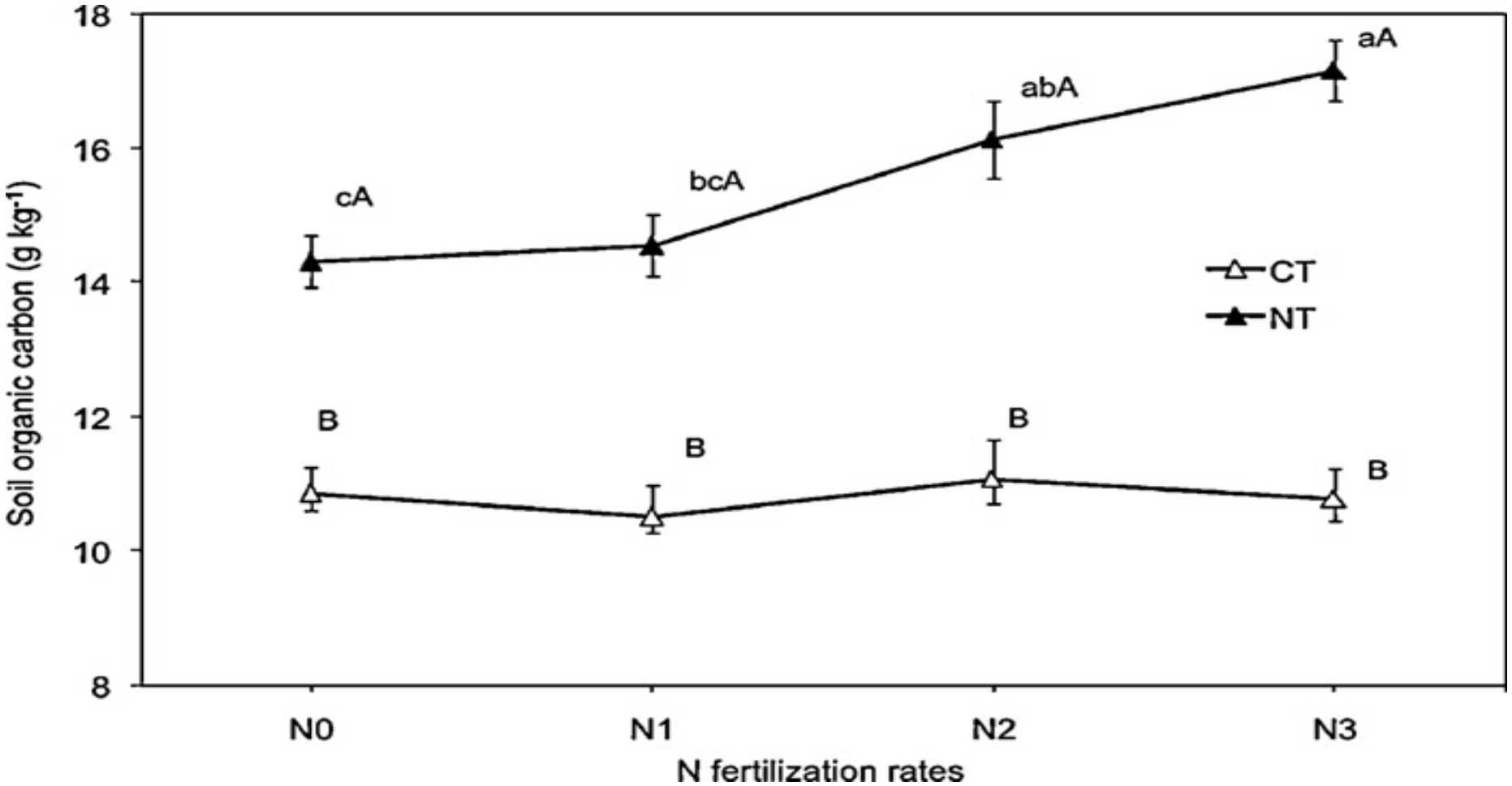


Figure 4: Predicted (Feng and Li, 2002) and experimentally measured soil organic carbon in Rothamsted continuous wheat plots (Data from Jenkinson, 1990). Treatments are: annual addition of manure at 3 t carbon/ha (●); annual adddition of fertilizer at 144 kg N, 35 kg P, 90 kg K and 12 kg Mg/ha (■); control (♦). Solid lines are predictions by K-Model.

Nitrogen and tillage interaction

- **No-tillage, N fertilization, and cover crops can interact positively to improve SOC and STN.**
- **While NT conserves SOC by reducing the rate of residue Decomposition and C input (Franzluebbers et al., 1995),**
- **N fertilization and cover crops can increase soil C input by increasing biomass production and residue addition to the soil (Sainju et al., 2002).**

Nitrogen and tillage interaction



SOC in 0-10 cm depth under CT and NT systems at different rates of N fertilizers

Mazzoncini et al. (2011)

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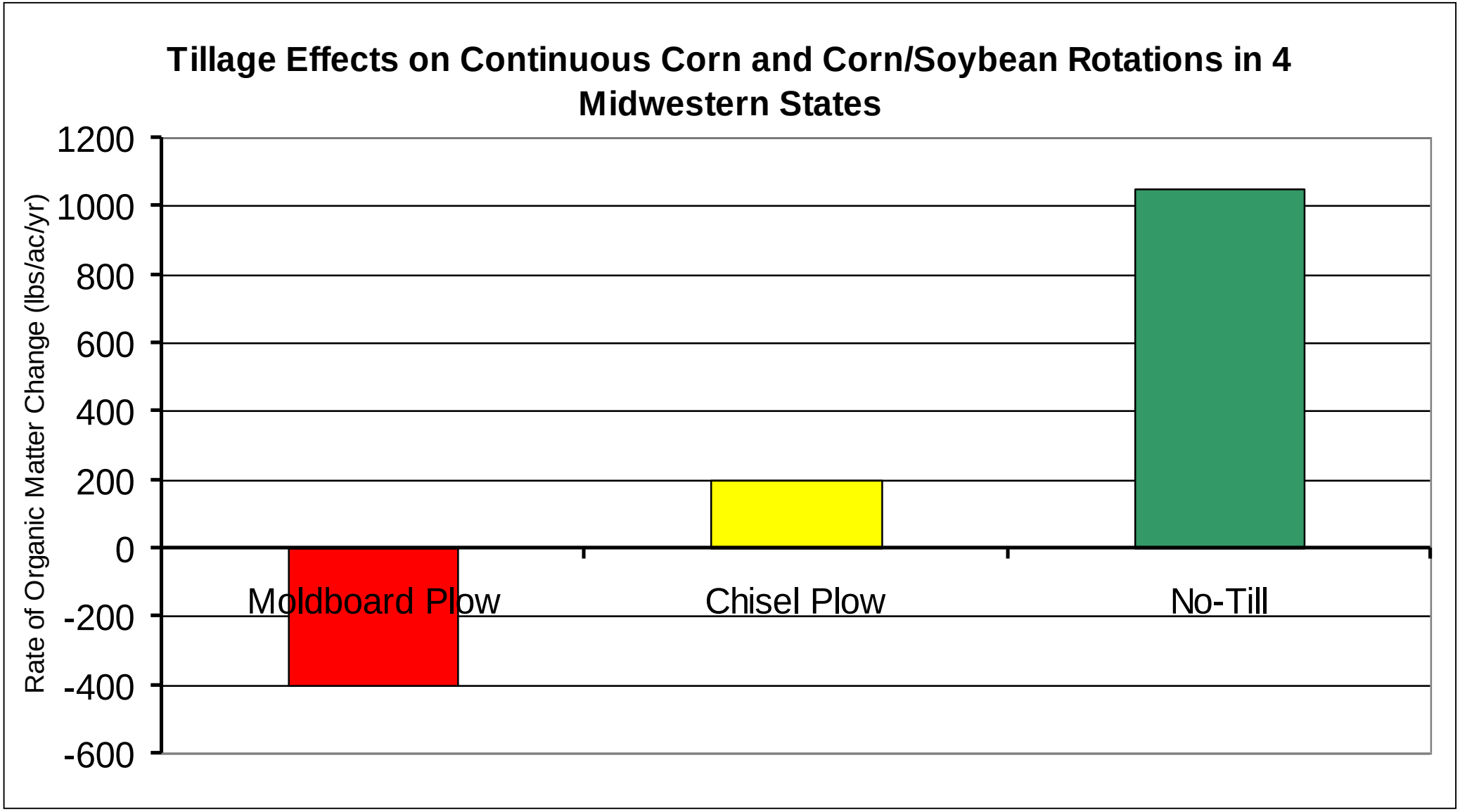
How does tillage affect SOM decomposition?

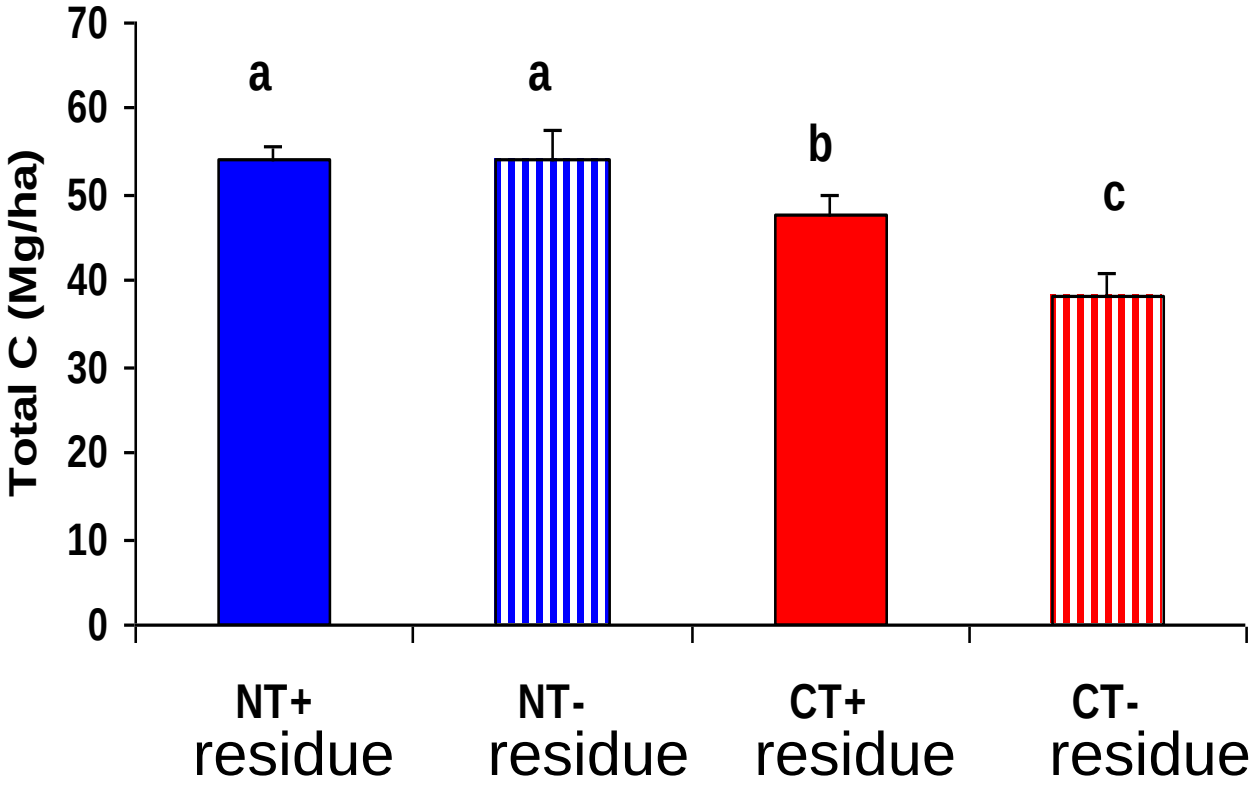
- Residues are mixed with soil
  - Physically breaks residue into smaller pieces
  - Intimate contact between soil and residue
- Aerates soil
- Breaks apart soil aggregates, exposes protected SOM to decomposition
- Promotes erosion losses

How much does tillage impact SOM?



Adapted from Richard Stehouwer- Penn State CMEE

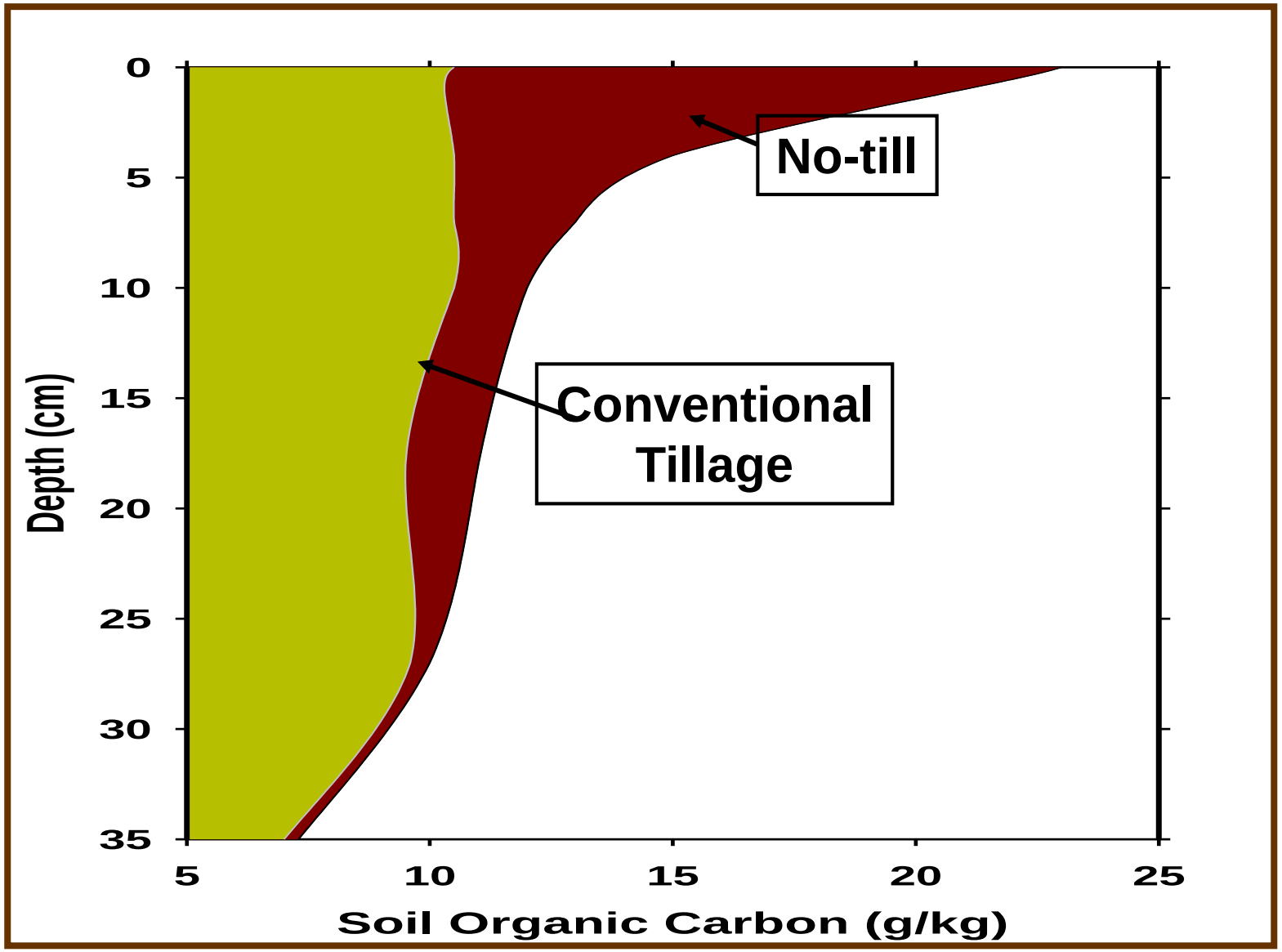
30 year study in Connecticut
Tillage and residue management



Data from B. Hooker, T. Morris, and Z. Cardon. Department of Ecology and Evolutionary Biology University of Connecticut

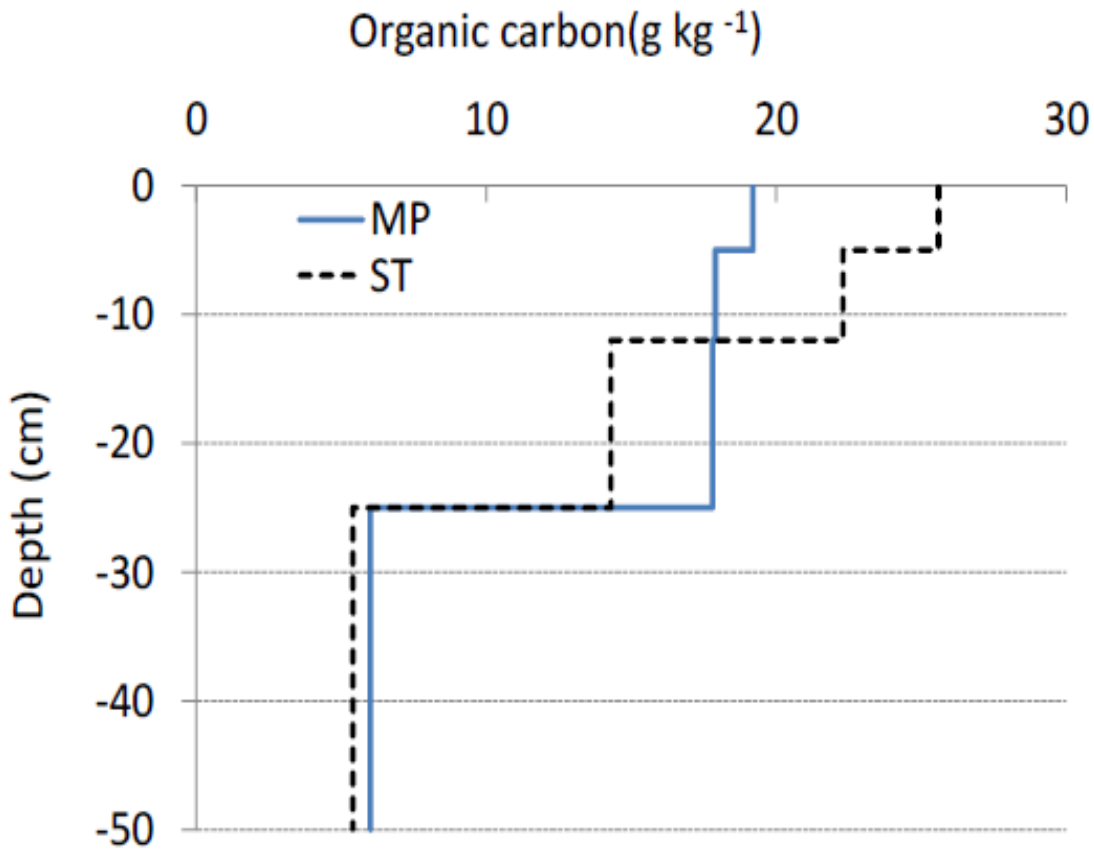
Adapted from Richard Stehouwer- Penn State CMEE

Distribution of organic matter in soil under conventional and no tillage



Adapted from Richard Stehouwer- Penn State CME

Reduced tillage for C sequestration?



Different stratification of SOC but no differences in SOC stocks between mouldboard ploughing (MP) and shallow tillage(ST) after 35 years at Ultuna, Sweden (1974-2009)

Etana, et al., 2013. SCS

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Growing crops with contour hedgerows of Leucaena leucocephala is an example of a wide range of agroforestry systems (Lal 2004)

No-Till Farming as an Emerging Global Technology

Lal (2019) Seminar at NMBU

Water Management and SOC sequestration

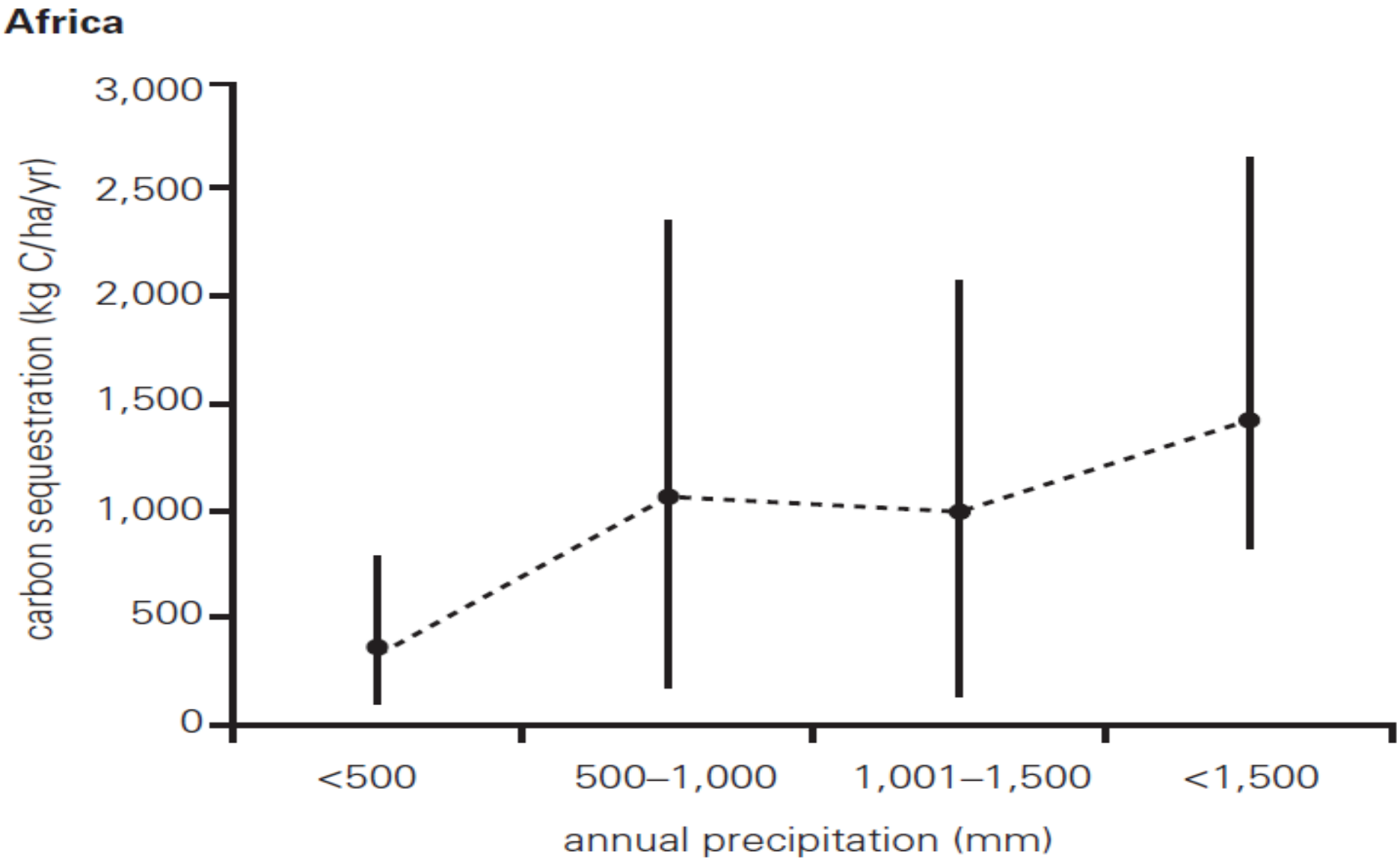
Water management and SOC

Improved water productivity in agriculture is achieved by:

- Reducing water loss
- Harvesting water
- Managing excess water
- Maximizing water storage
- Distribution efficiency of irrigation water

All lead to SOC sequestration but irrigation plays a most important role.

FIGURE 3.2: Soil Carbon Sequestration and Precipitation



Source: The World Bank Report No.GLB(2012)

Water management and SOC sequestration rate (kg C ha^{-1} yr^{-1})

Practice	Mean	Number of Estimate
Africa		
Rainwater harvesting	839	33
Cross-slope barriers	1193	22
Terracing	421	15
Asia		
Rainwater harvesting	1086	4
Improved irrigation	1428	10
Latin America		
Improved irrigation	571	34

Source: The World Bank Report No.GLB(2012))

Potential of C sequestration

Potential Rates of Soil Organic Carbon Sequestration

Land use and management	Temperate climate		Tropical climate	
	humid	dry	humid	dry
	- Mg C ha^{-1} yr^{-1} -			
Conservation tillage	0.5 - 1.0	0.25 - 0.5	0.25 - 0.5	0.1 - 0.25
Cover cropping/cropping systems	0.2 - 0.5	0.1 - 0.2	0.1 - 0.2	0.05 - 0.1
Integrated nutrient management/manuring	0.3 - 0.6	0.2 - 0.4	0.2 - 0.4	0.1 - 0.2
Water management/irrigation	-0.1 to -0.2	0.25 - 0.5	0.05 - 0.1	0.2 - 0.4

Negative sequestration in humid climates is caused by drainage of wetlands.

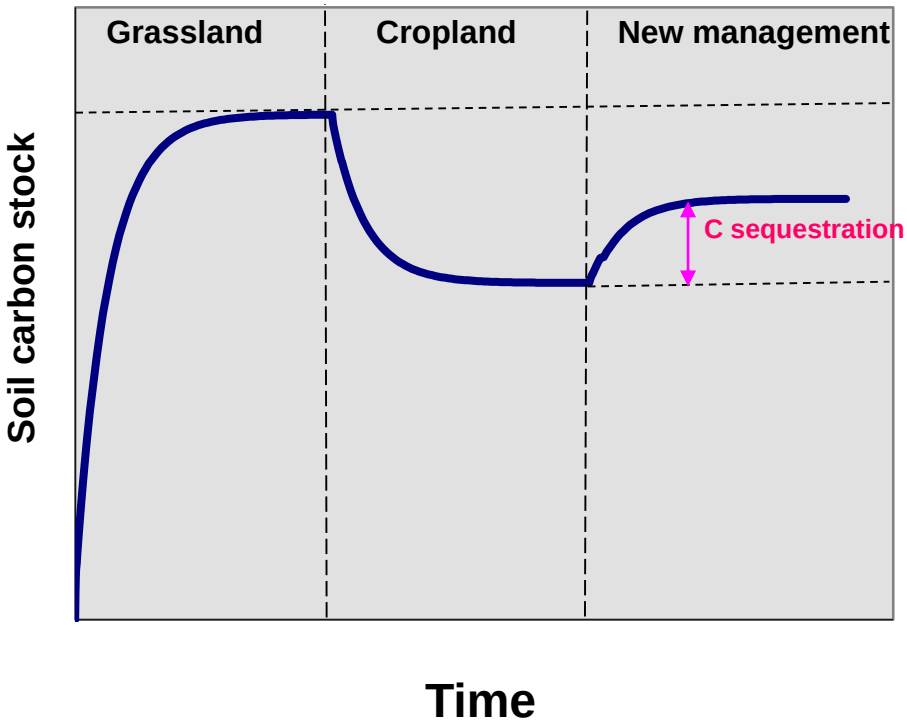
Lal (2006)

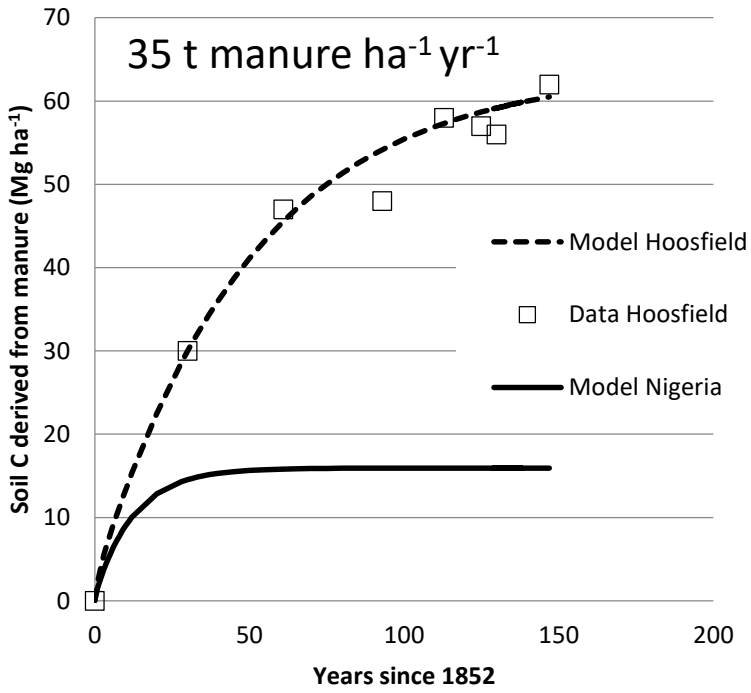
SOC sequestration rate in top soil (0-25cm) in the period 1953-2001(48 yrs)

Treatment	Bulk density (Mgm^{-3}) 0-25 cm	Total SOC kg SOC ha^{-1} 0-25cm	Change in SOC as copmared to Rot1	SOC sequestration rate
Rot1- 6 yrs grain	1.58	111583	0	0
Rot2- 3yrs grain+ 3yrs row crops	1.62	114040	2457	51
2 yrs grain+4 yrs madow	1.48	127950	16367	341

Holeplass et al.(2004)

Soil C sequestration is finite, reversible and dependent on climate





Data from Johnston et al., 2009. Adv. Agron. 101

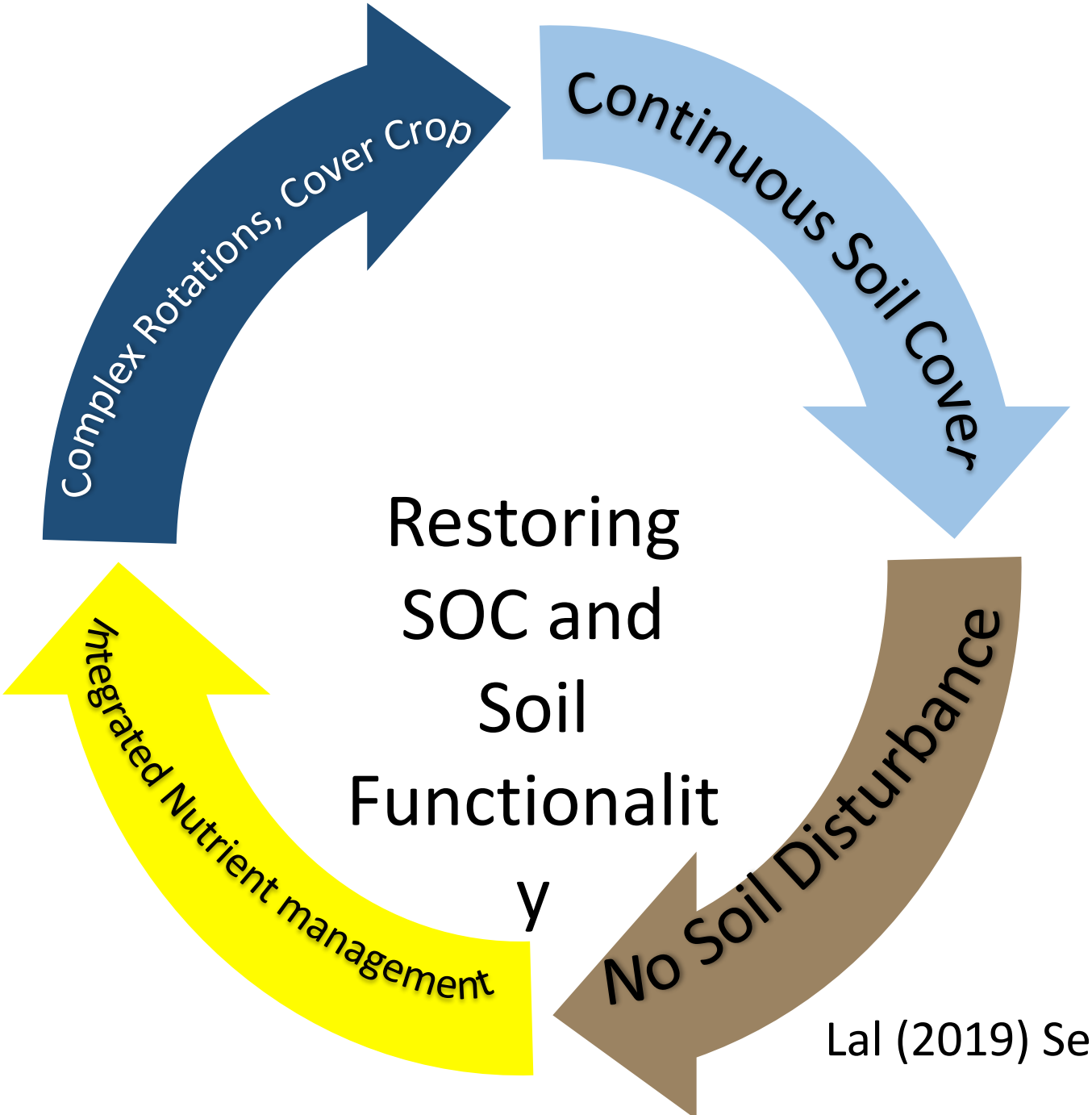
90% of the effect will be realised within

- 100 years in Nordic climates
- 20 years under tropical conditions

C sequestration - less effective in warm/moist climates

SOC , Soil Health and Food Productivity

Managing Soil Carbon and Restoring Soil Health



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MEETING FOOD DEMAND BY 2050

The world produces enough food to feed 10 billion people. Thus, food and nutritional security must be achieved by:

- **Reducing** waste (30-50%),
- **Increasing** access to food by addressing poverty, inequality, instability,
- **Improving** distribution,
- **Increasing** use of **pulses** and plant-based protein,
- **Accepting** personal responsibility, and
- **Increasing** agronomic practices, restoring degraded lands, enhancing BNF by land, agricultural land for nature conservancy without any co agro-ecosystems, through

We must reconcile the need of advancing food and nutritional security with the necessity of improving the environment

sustainable eco-intensification and restoration of soil health.

Lal (2019) Seminar at NMBU

Restoring SOC Pool by 1 Mg C ha^{-1} yr^{-1} and Food Production in LDCs

Crop	Area (10^6 ha)	Production Increase (10^6 Mg yr^{-1})
Cereals	430	21.8 - 26.3
Legumes	68	2.0 - 3.2
Tubers	34	6.6 - 11.3

Lal (2006)

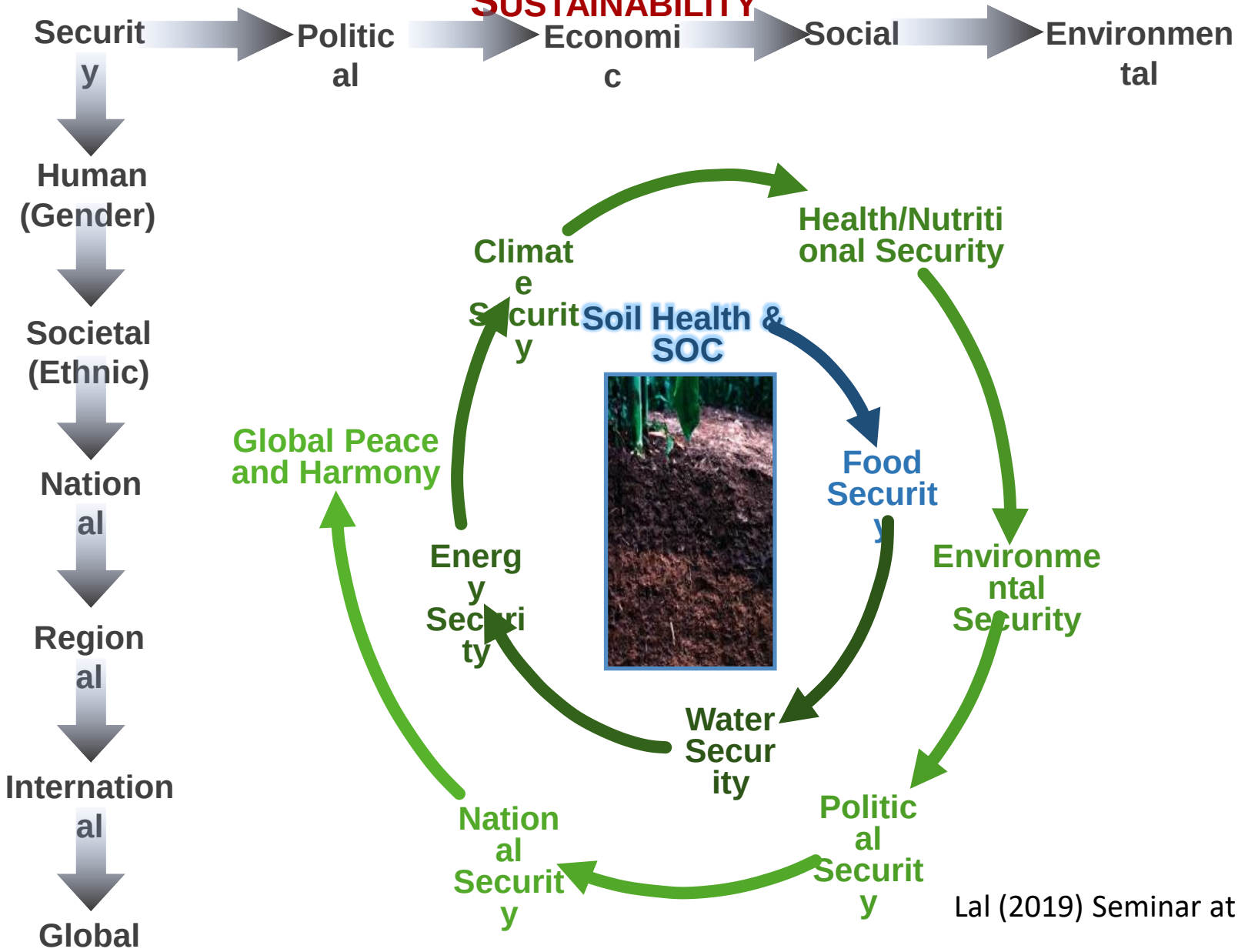
Climate Change and Crop Yield Decline by 2050

Crop	Yield decline (%)
Maize (Irrigated)	8.6 to 13.2
Maize (Rainfed)	9.1 to 16.0
Rice (Irrigated)	7.4 to 26.8
Rice (Rainfed)	6.8 to 13.1
Wheat (Irrigated)	29.4 to 41.9
Wheat (Rainfed)	18.0 to 28.3

WFP (2009)

CenterCarbOn sequestration

Securitization Of Food and The Environment Through Soil Sustainability



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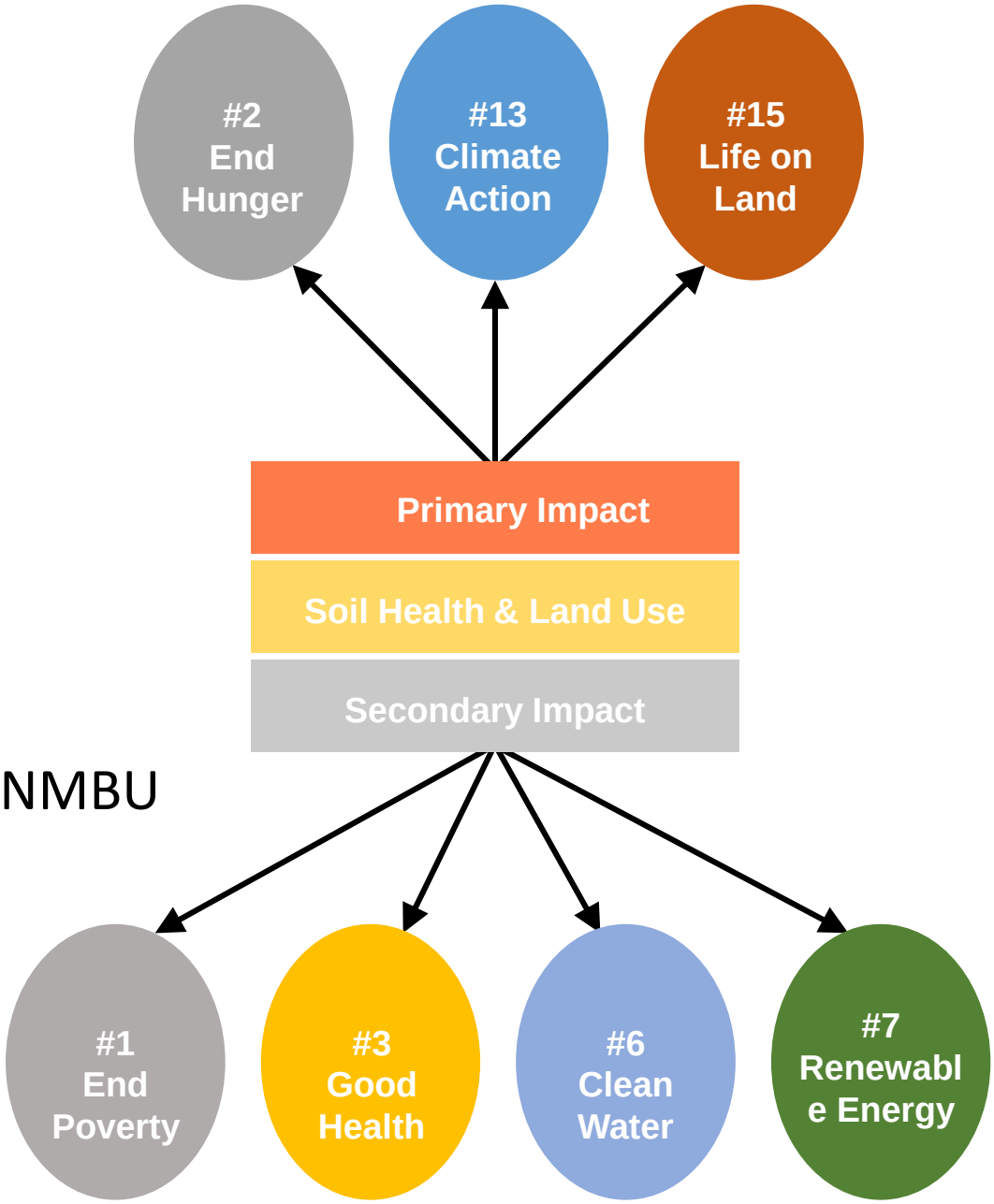
Soil Carbon and Sustainable Development Goals (SDGs)



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