Organic matter dynamics and indicators of carbon sequestration in soils

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Outlines

- Soil organic matter (SOM) dynamics
- Composition and quality of SOM
- SOM composition and quality
- Indicators of carbon sequestration
- Conclusions

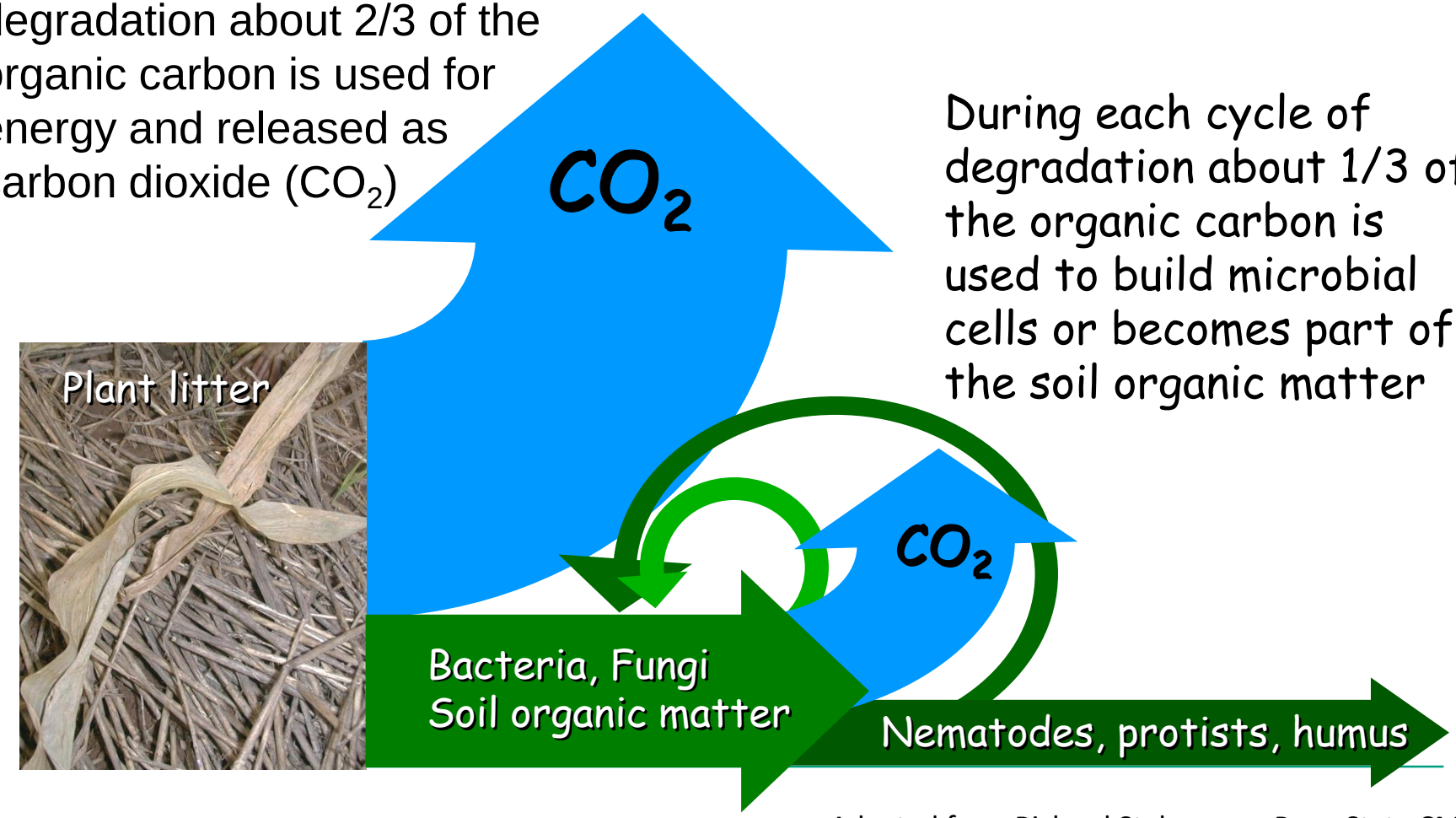
Soil organic matter (SOM) dynamics

Organic matter decomposition

Carbon and Nitrogen Cycling

During each cycle of degradation about 2/3 of the organic carbon is used for energy and released as carbon dioxide (CO_2)

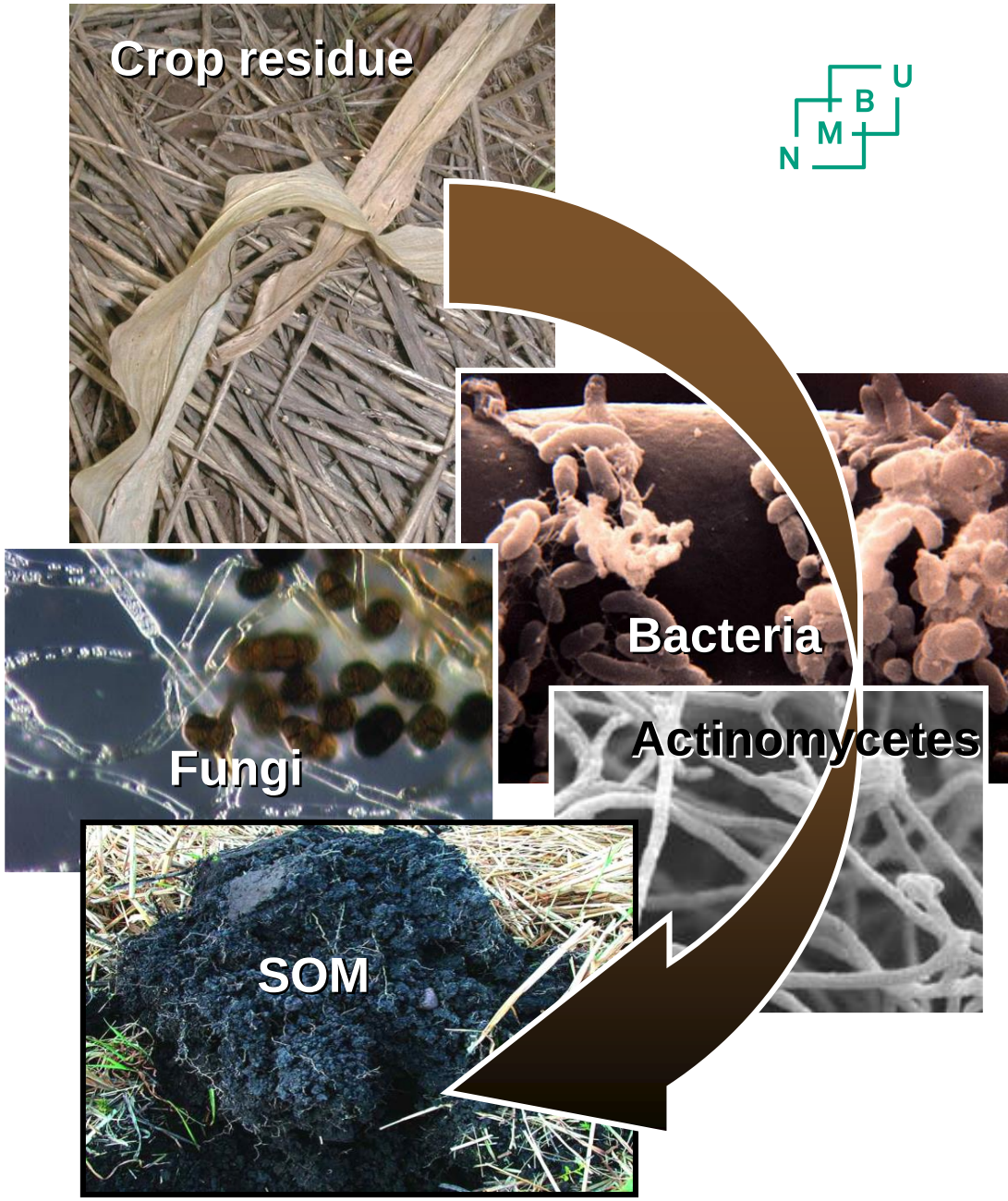
During each cycle of degradation about 1/3 of the organic carbon is used to build microbial cells or becomes part of the soil organic matter



Adapted from Richard Stehouwer- Penn State CME

What is Soil Organic Matter?

- All material in soil that contains carbon.
- SOM is derived from
  - Plant residue
  - Animal remains
  - Living soil microbes
- Over time microbes transform fresh organic material into stable soil organic matter



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Why should you care about soil organic matter (SOM)?

Improves Soil Physical Properties

- Increased granulation and aggregate stability
- Makes heavy soils easier to work
- Increases water infiltration rates
- Increases water holding capacity
- Reduces compaction and hard setting
- Decreases runoff and erosion

If your soil looks like this…

Y[illegible]s!

Adapted from Richard Stehouwer- Penn State CME

Why should you care about soil organic matter (SOM)?

SOM Improves Soil Chemical Properties

- Increases CEC and store plant nutrients
- Increases pH buffering
- Reduces Aluminum, Iron, and Manganese toxicity in acidic soil
- stimulation of beneficial soil life
- organic humates are a catalyst for increasing soil C levels

Adapted from Richard Stehouwer- Penn State CME

Why should you care about soil organic matter (SOM)?

- SOM Improves Soil Biological Properties
  - Greater abundance, diversity and activity of soil microbes
  - Increased nutrient cycling
  - Increased root elongation and abundance
  - Increased access to water and nutrients

Soil Organic Matter is Dynamic

Rate of decomposition is affected by:

1.

Environmental Conditions

- Temperature
- Moisture
- Aeration (oxygen)
- Soil texture
- Soil pH
- Soil fertility

2.

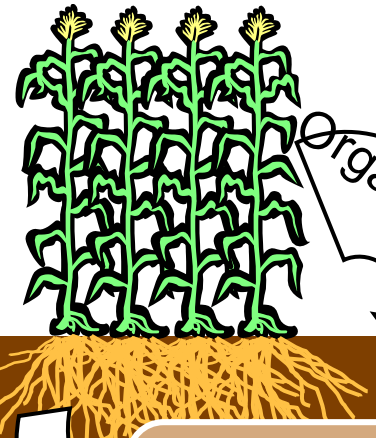
Quality of added Organic Material

- **C/N ratio**
- **Composition/Age**
- **Physical properties and placement**
- **Fresh vs. "processed"**

Adapted from Richard Stehouwer- Penn State CME

All organic matter in soil is not equal

3 pools of soil organic matter



Organic Material

CO_2

Active SOM
1 – 2 yrs
C/N ratio 15 – 30

- **Recently deposited organic material**
- **Rapid decomposition**
- **10 – 20% of SOM**

Slow SOM
15 – 100 yrs
C/N ratio 10 – 25

- **Intermediate age organic material**
- **Slow decomposition**
- **10 – 20% of SOM**

Passive SOM
500 – 5000 yrs
C/N ratio 7 – 10

- **Very stable organic material**
- **Extremely slow decomposition**
- **60 – 80% of SOM**

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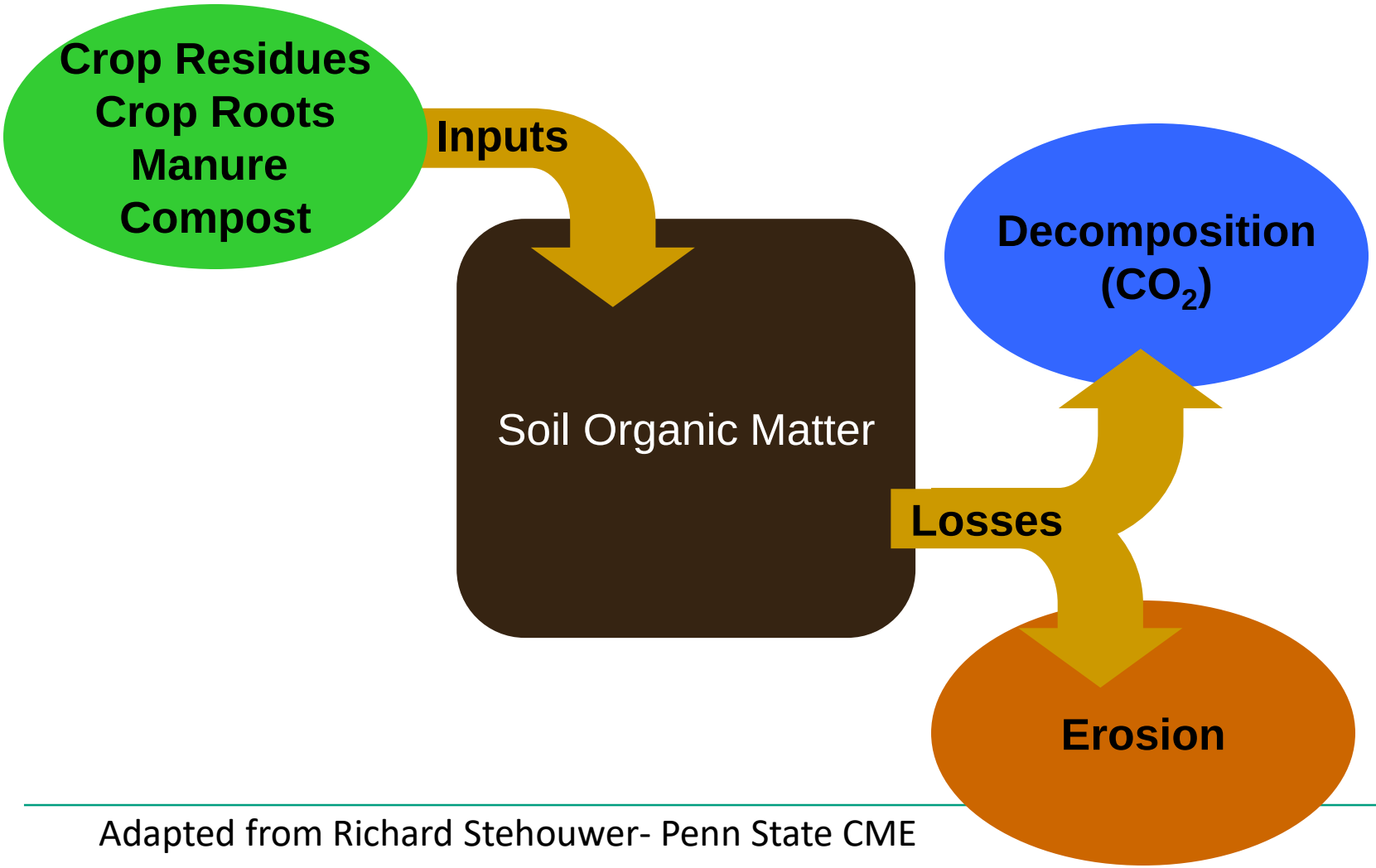
- **There is a constant turnover of organic material in soil.**
- **The quantity of SOM depends on the balance between inputs and losses of organic material**



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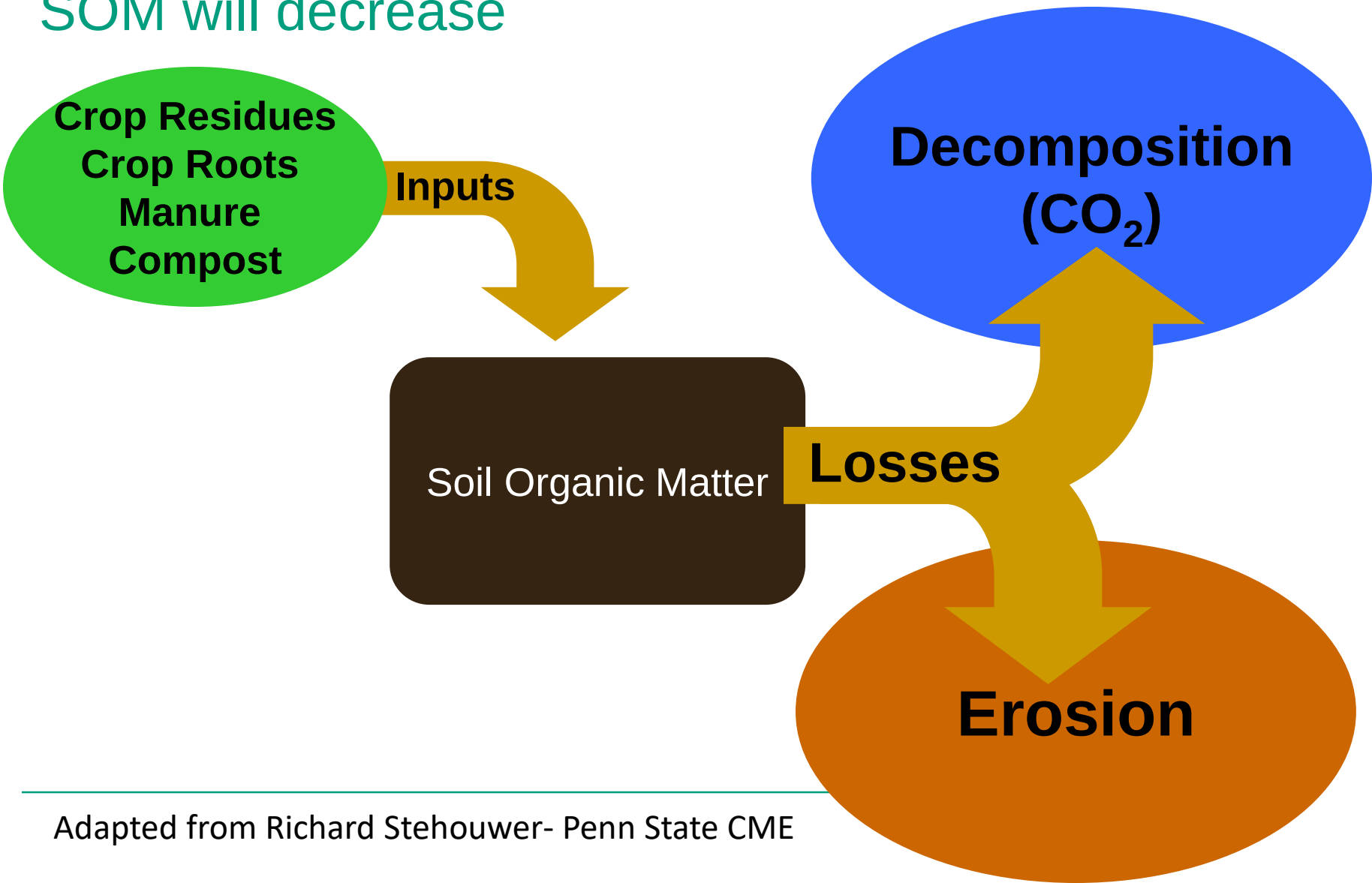
If losses increase and inputs remain constant, SOM will decrease



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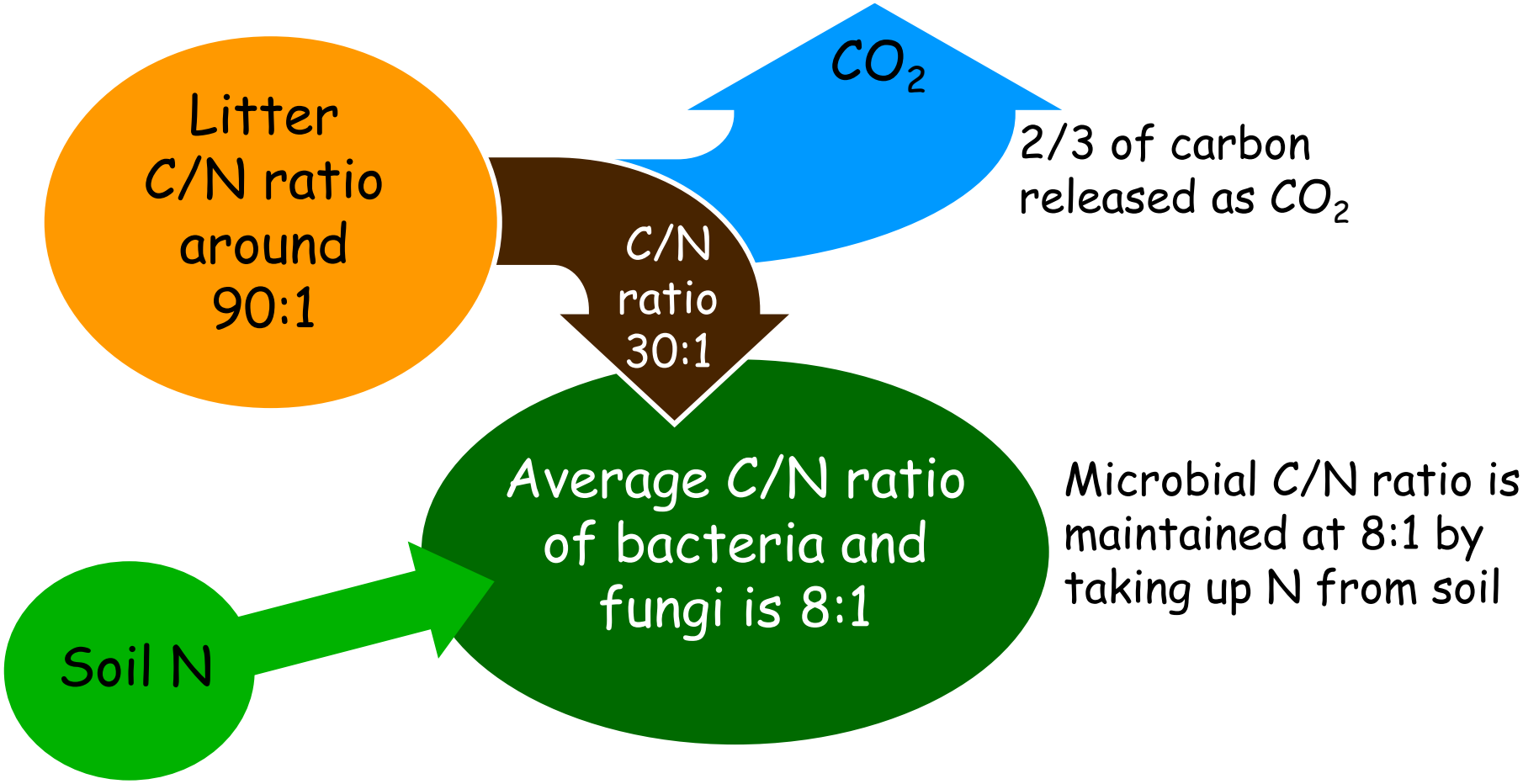
Organic matter decomposition

Carbon and Nitrogen Ratios



Immobilization

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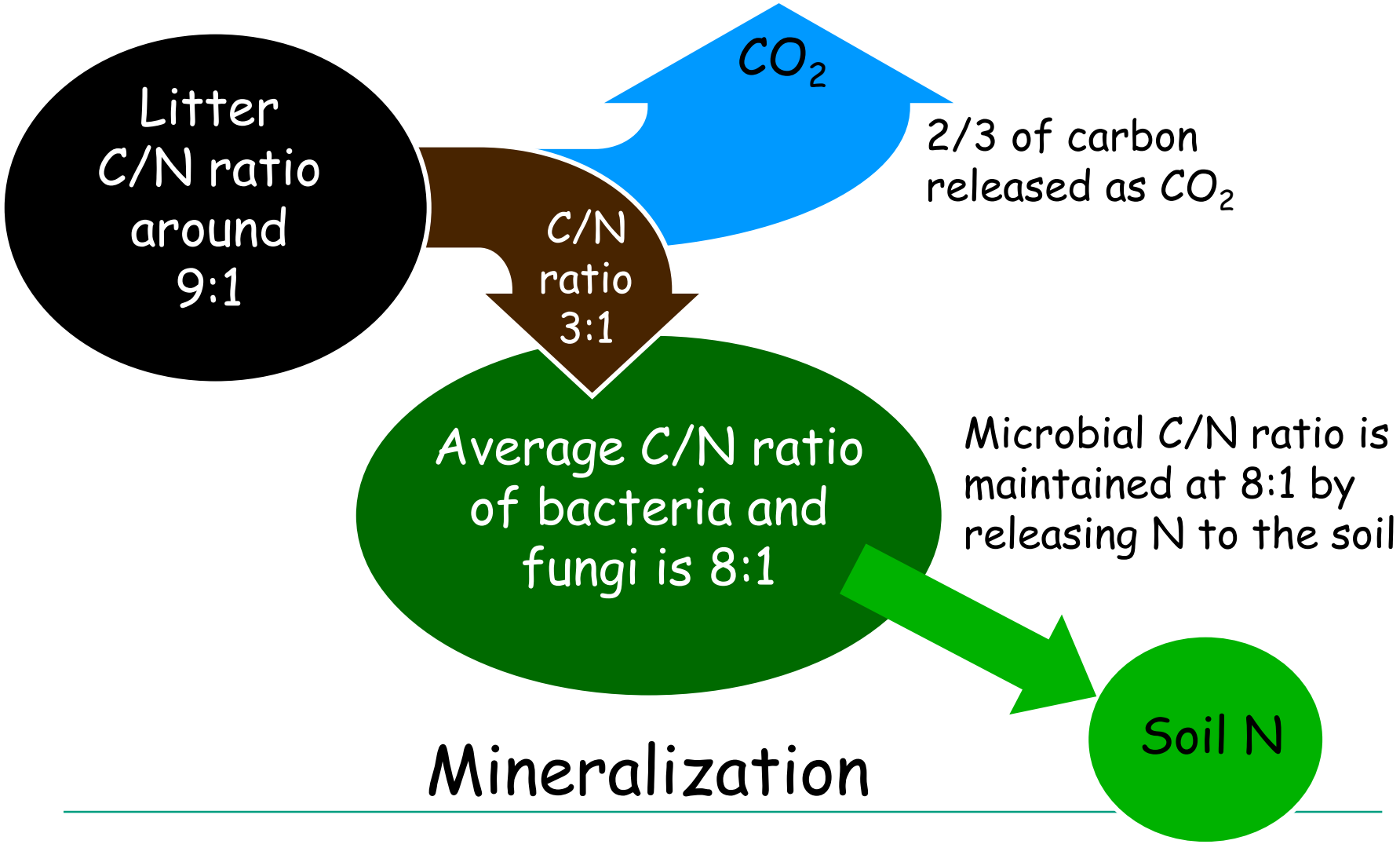
Organic matter decomposition

Carbon and Nitrogen Ratios



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SOM composition and quality

SOM consists of the following fractions

- Fulvic acids: soluble in water under all pH,
- Humic acids: soluble in water, except for conditions more acid than pH 2,
- Humin: not soluble in water at any pH but in a strong base (e.g. NaOH),
- Inert or black carbon, a fraction of humin, not oxidized by chemical, photo and thermal oxidation, and hence very long lasting

Effect of crop rotation and fertilizer type on SOC fractions in 0-10 cm soil

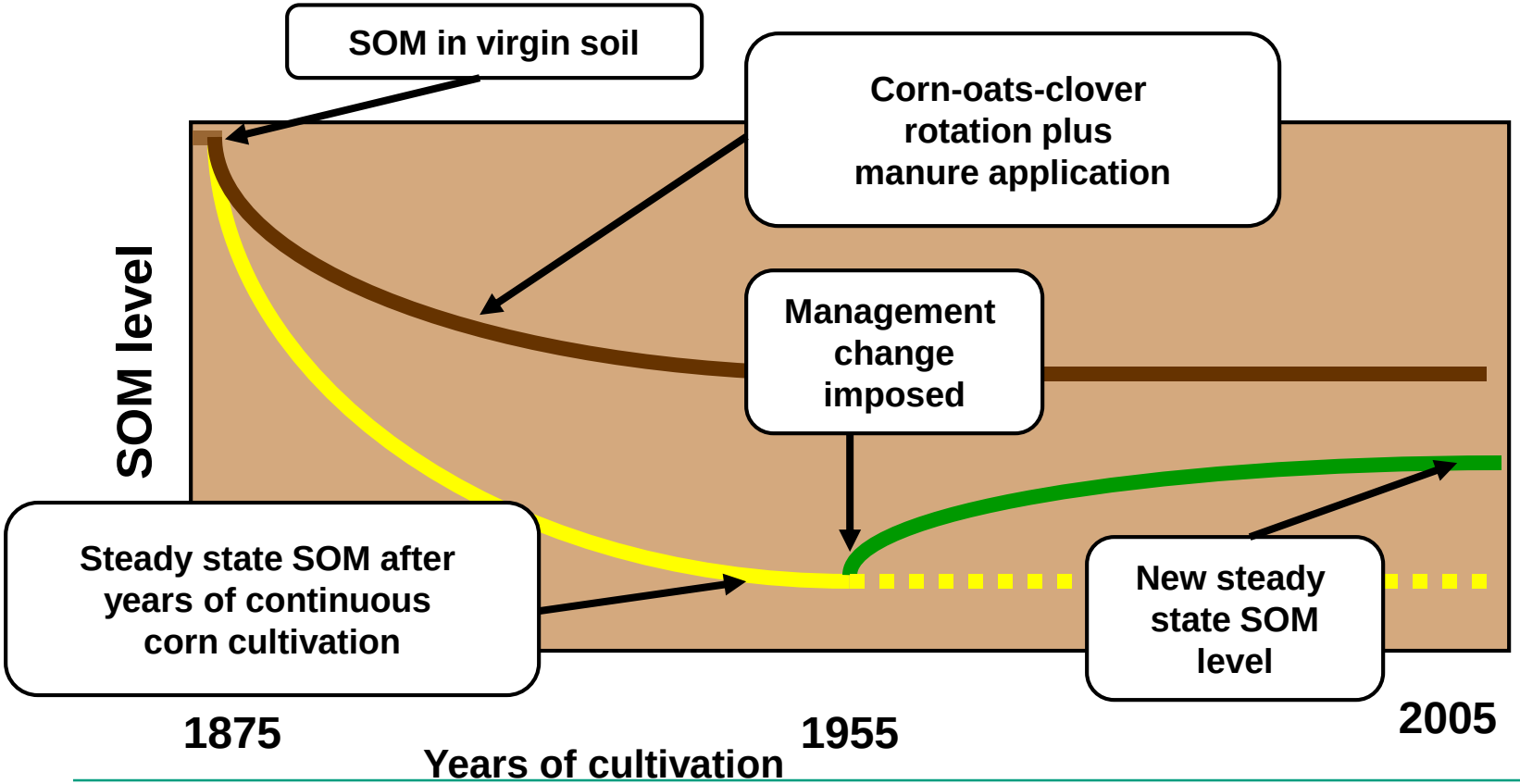
Treatment	FA-C (mg g^{-1})	HA-C(mg g^{-1})	Humin-C (mg g^{-1})	Black Carbon (mg g^{-1})
Crop rotation				
Grain	8.7b(30)	6.9b(24)	12.6b (43)	1.9b (6.6)
Grain+grass	9.5a(27)	9.1a(26)	15.4a (44)	2.5 a(7.1)
Fertilizers				
NPK	9.0a(29)	7.5b(24)	13.9b (44)	2.3a (7.2)
FYM	9.3a (28)	8.6a (26)	14.6a(44)	2.4a(7.0)

Values with different letters in the same column are significantly different at P=0.05. Values in brackets are C content of SOC. FA-C = Fulvic acid and HA-C =Fulvik acid.

Yang et al. (2004)

SOM will not continue to increase or decrease indefinitely

When inputs or losses are changed, SOM quantity changes to a different level and a new steady state condition is reached. From Morrow plots at the University of Illinois



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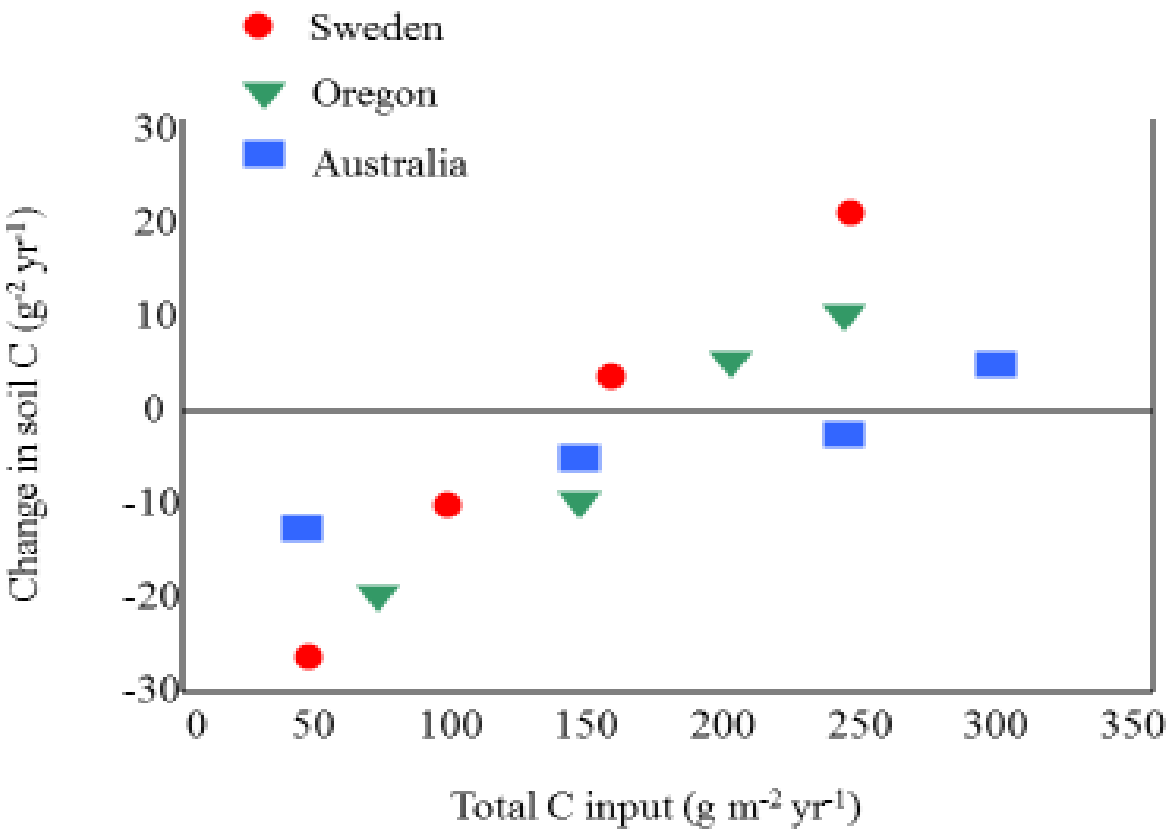
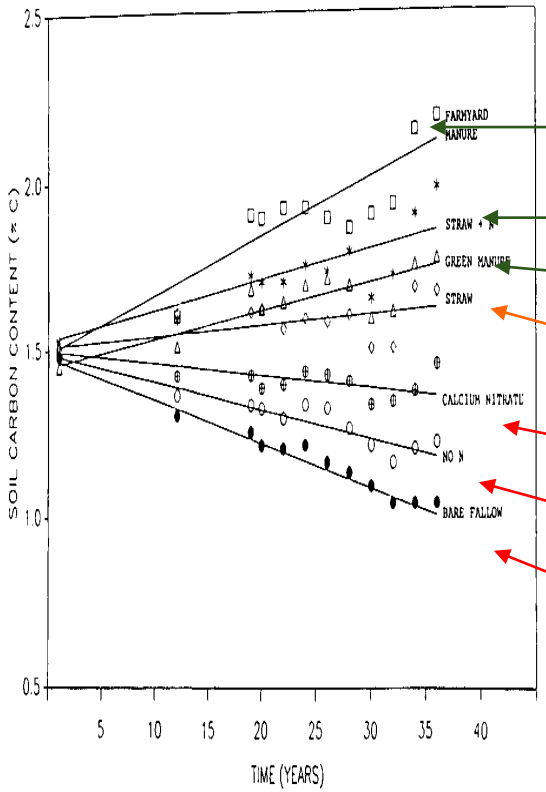


Comparison of change in soil organic C in relation to total organic C inputs at three different locations (after Parson et al., 1996). Carter (2002) CMASC 9-04

Effects of long-term use of organic ammendments on SOC in Swedish soils

Annual changes :

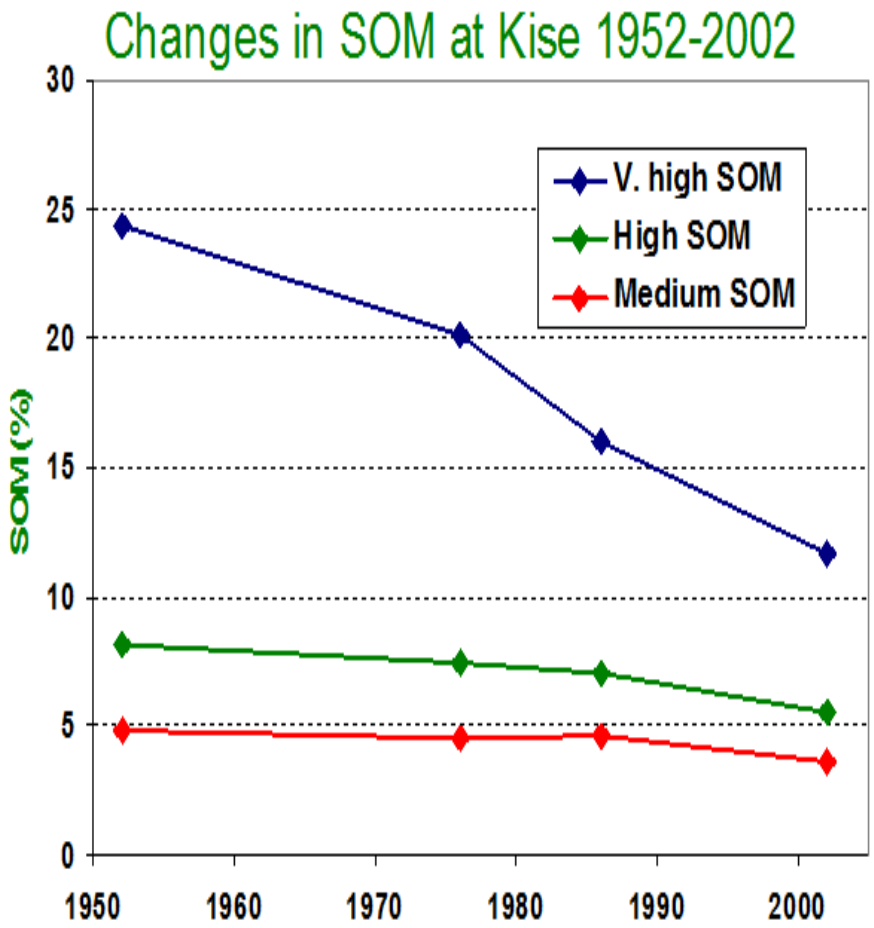
kg C/ ha



Farmyard manure	+430
Straw with N fertilizer	+220
Green manuring	+190
Straw without N fertilizer	+70
No straw, with N fertilizer	-100
No straw, without fert.	-220
Bare fallow	-310

(Persson & Kirchmann 1994)

SOM change at different levels



'Rule of thumb' model:

20% to 15% takes 20 years

15% to 10% takes 35 years

10% to 5% takes 100 years

5% to 3% takes 135 years

Rilley (pers.com)

Indicators of carbon sequestration

Soil quality

The term soil quality implies "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation"

(NRCS, 2008).

Soil Quality

Soil organic matter (SOM) strongly impacts soil quality, and interacts with soil chemical, physical and biological parameters, which determine plant growth.

It is widely recognized that continuous NT farming leads to stratification of the SOM pool,

with the highest accumulation in the surface layer (Rasmussen and Parton, 1994; Franzluebbers et al., 2007).

Stratification ratio (SR)

The stratification ratio (SR) of SOM can be used as an indicator of the soil quality under diverse tillage methods (Franzluebbers et al., 2007).

SR is defined SR as the ratio of parameter values in the soil surface with that at a lower depth, such as the bottom of the tillage layer.

Stratification ratio (SR)

- SR ranges from 1.1 to 1.9 for CT and 2.1 to 4.1 for NT (Franzluebbers et al., 2007).

- The SR of SOC was proposed as an efficient indicator of soil quality (Franzluebbers, 2002;), and its increase can be related to the rate and amount of SOC sequestration (Franzluebbers et al. 2007)

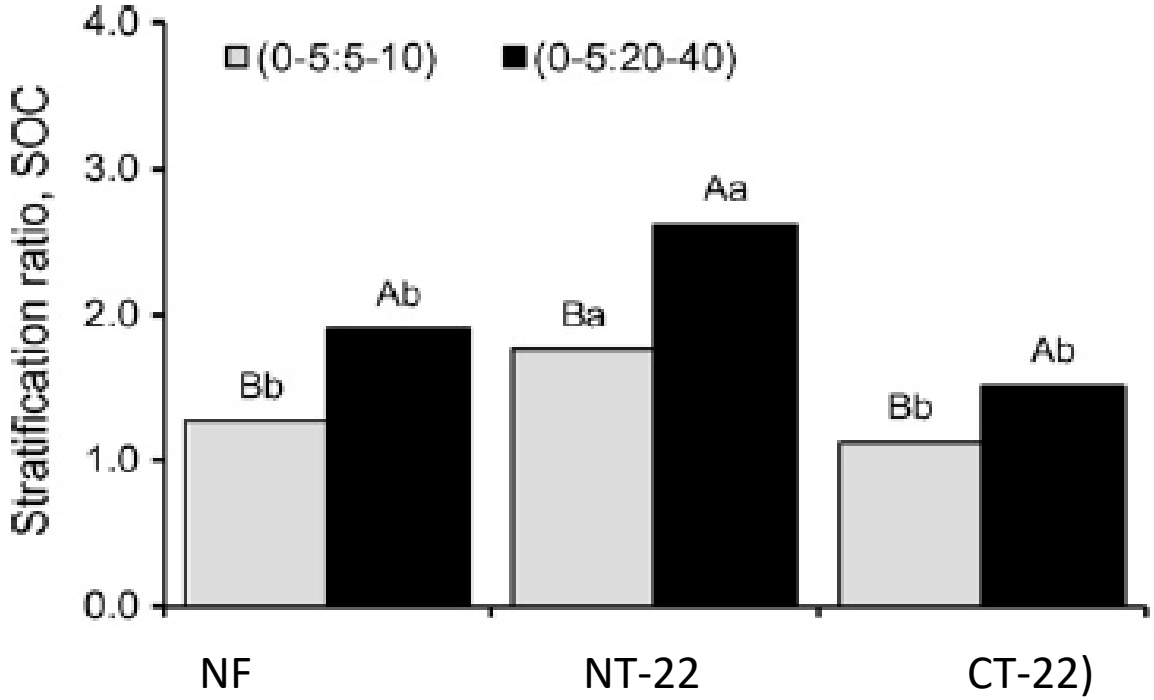


Fig. Comparison of stratification ratio of SOC among native field (NF), no-tillage 22 years (NT-22) and conventional tillage 22 years (CT-22). The upper case letters represent the comparisons by Tukey test (LSD0.05) between SR for 0–5:5–10 cm and 0–5:20–40 cm ratio depth within each treatment and the lower case letters represents the comparisons among tillage systems within each ratio depth

Adapted from Sa and Lal (2009)

Fractions of OM

- Soil suspension wet sieved through a 212-µm opening sieve to obtain the 212– 2000 µm fraction.
- The fractions remaining on the sieve washed with deionized water.
- The washing was added to the suspension passed through a 212-µm sieve.
- The fraction remained that was between 53 and 212 µm in size represented the particulate organic carbon (POC).

Fractions of OM

- Soil suspension was passed through 53 µm sieves to obtain the fraction that represented the stable C and N pools. Soil suspension in the 1-L glass cylinder was flocculated with 0.77 g $CaCl_2$.

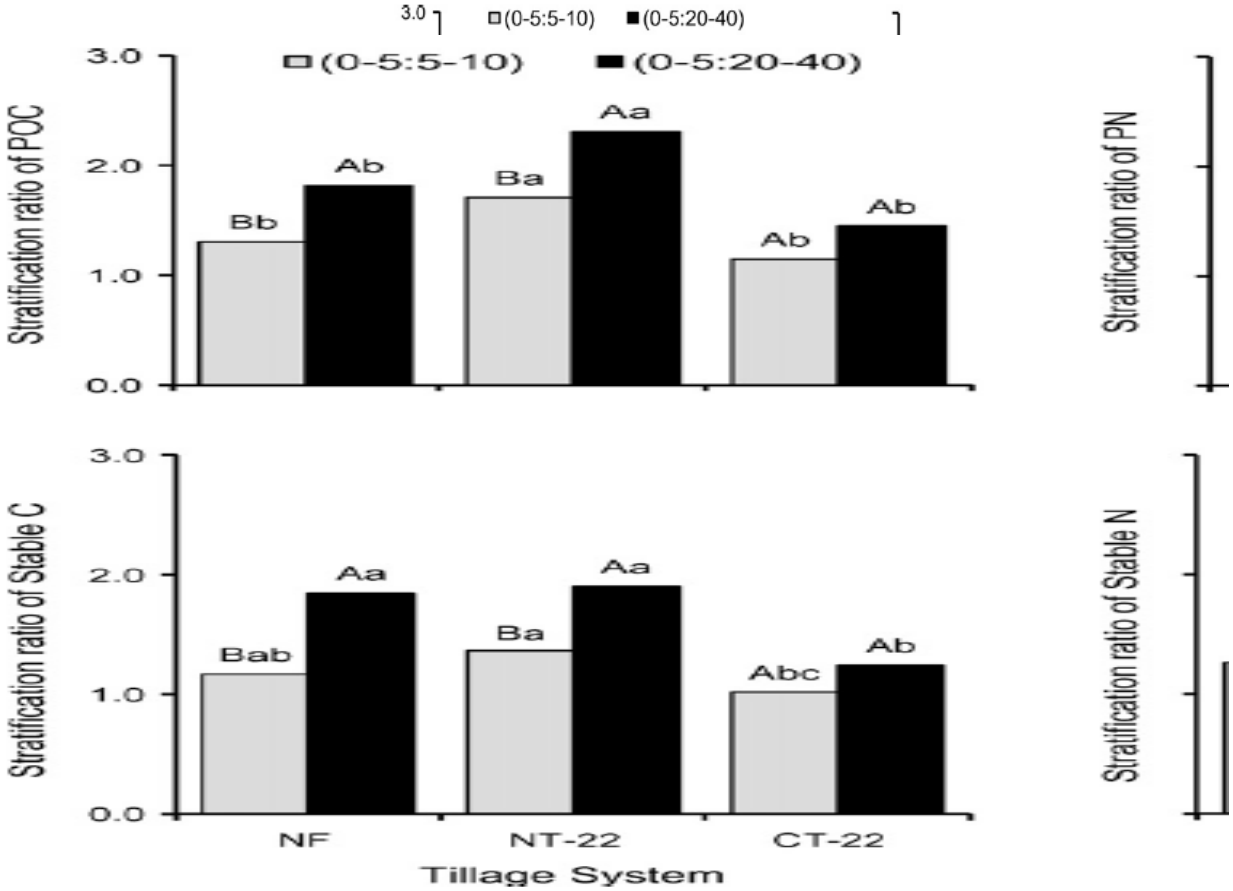


Fig. Comparison of stratification ratio of particulate organic carbon (POC) and stable carbon (SC) among native field (NF), notillage (NT)22 years (NT-22) and conventional tillage 22 years (CT-22). The uppercase letters represent the comparisons by Tukey test (LSD0.05) between SR for 0–5:5–10 cm and 0–5:20–40 cm ratio depth within each treatment and the lowercase letters represent the comparisons among tillage systems within each ratio depth.(Adapted from Sa and Lal (2009)

Other indicators

- 1. Changes in the amount of carbon stored by ecosystems should not be obscured by changes in the *areal extent* of major ecosystem types.

- 2. Indicators should be sensitive to major changes in carbon stocks, especially in carbon-dense systems and lands undergoing conversion to new cover types, climate regimes, or disturbance patterns. **Negra et al. (2008)**

Other indicators

- For example, wetlands constitute a relatively small percent of the U.S. by area, but they have the potential to release or take up large quantities of carbon in response to changing hydrologic conditions (Johnson et al., 2005).

- To facilitate detection of meaningful patterns in carbon storage, it is important to measure both *changes* in carbon stocks over units of time, as well as *total* carbon stocks.

Other indicators

- While tracking rates of change is important for identification of major shifts in net gain or loss of carbon,

It is also important to characterize, to the extent possible, the total quantity of carbon stored in ecological compartments to understand the scale of historical and possible future shifts. **Negra et al. (2008)**

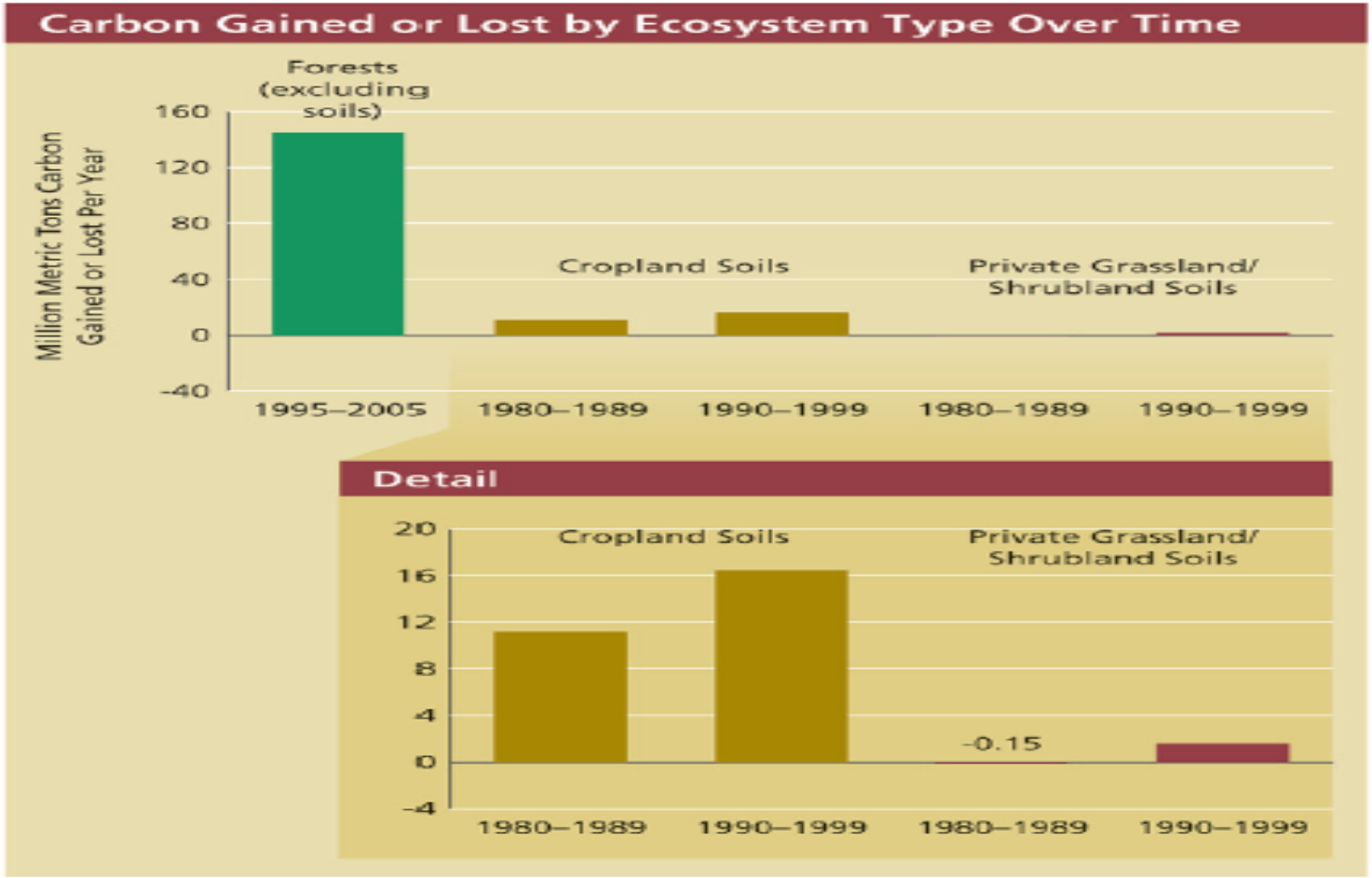
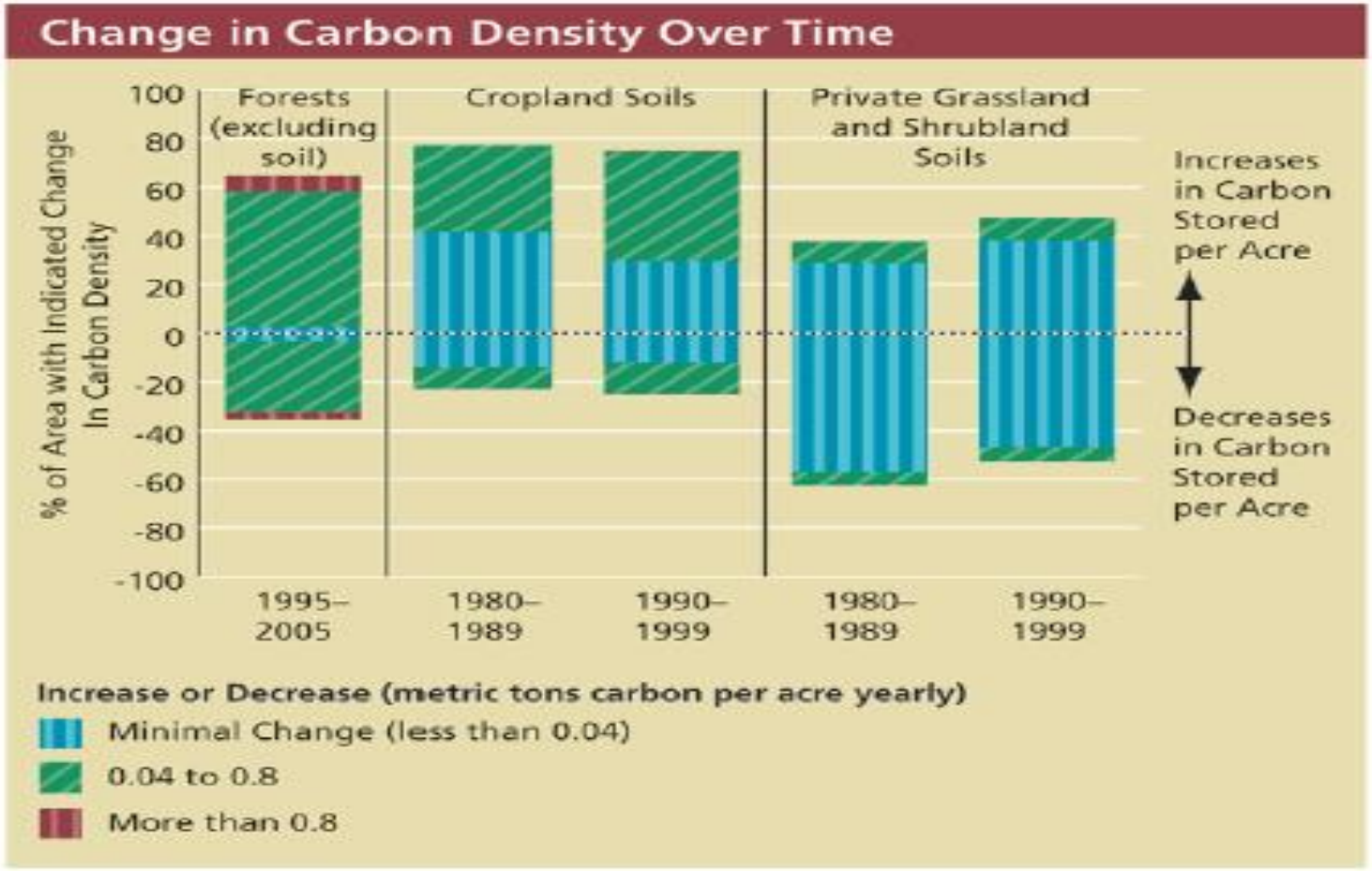


Fig. Carbon gained or lost, by ecosystem type, over time. Estimates for forests provided by USFS for above- and below-ground biomass (excluding soil). Estimates for croplands, grasslands,and shrublands provided by NREL for soil carbon (top eight inches) on private lands only. Coverage: lower 48 states. Negra et al. (2008)



Change in carbon density, by ecosystem type, over time. Estimates are based on data shown in Fig. 1 and areal extent of forests,croplands, and grasslands and shrublands. Note unit conversion: 1 metric ton = 1.10 U.S. short tons; 1 acre = 0.40 hectare. Negra et al. (2008)

Rhizosphere soil indicators

- Different carbon indices have been used to assess C accumulation in the soils (Blair et al., 1995; Silva et al., 2014).

- The original carbon management index developed by Blair et al. (1995) is based on total and labile C, which can used to identify the key rhizosphere soil parameters influencing tree biomass and carbon density.
-

Rhizosphere soil indicators

- Total soil carbon (TC) was determined by dry combustion and labile carbon (LC) and microbial biomass carbon(MBC) were determined by following standard protocols (Blair et al., 1995; Vance et al., 1987).

- Non-labile carbon (NC) was calculated as the difference between TC and LC. These data were used to calculate the different carbon indices (modified from Blair et al. (1995)) as follows:

Rhizosphere soil indicators

- Carbon pool index (CPI)= TC(rhizosphere)/TC(non-rhizosphere) (1)

- Lability index (LI) =LC/NC (rhizosphere)/ LC/NC (non-rhizosphere) (2)

- An additional factor of microbial biomass carbon-based microbial index was introduced to calculate carbon accumulation index:

Adapted from Mukhapadhyay et al. 2016)

Rhizosphere soil indicators

- Microbial index (MI)= MBC/NC (rhizosphere)/ MBC/NC(non−rhizosphere) (3)

- Different types of carbon accumulation indices (CAIs) were calculated
- as follows:
- CAI−1 = CPI X LI (4)
- CAI−2 = CPI X MI (5)
- CAI−3 = CPI X LI X MI (6)

Adapted from Mukhapadhyay et al. 2016)

Rhizosphere soil indicators

- where CPI is the carbon pool index (Eq. (1)),
- LI is the lability index (Eq.(2)), and
- MI is the microbial index (Eq. (3)).
- CAI-1 depends on total and labile C, whereas microbial C is included in CAI-2 and CAI-3.

Adapted from Mukhapadhyay et al. 2016)

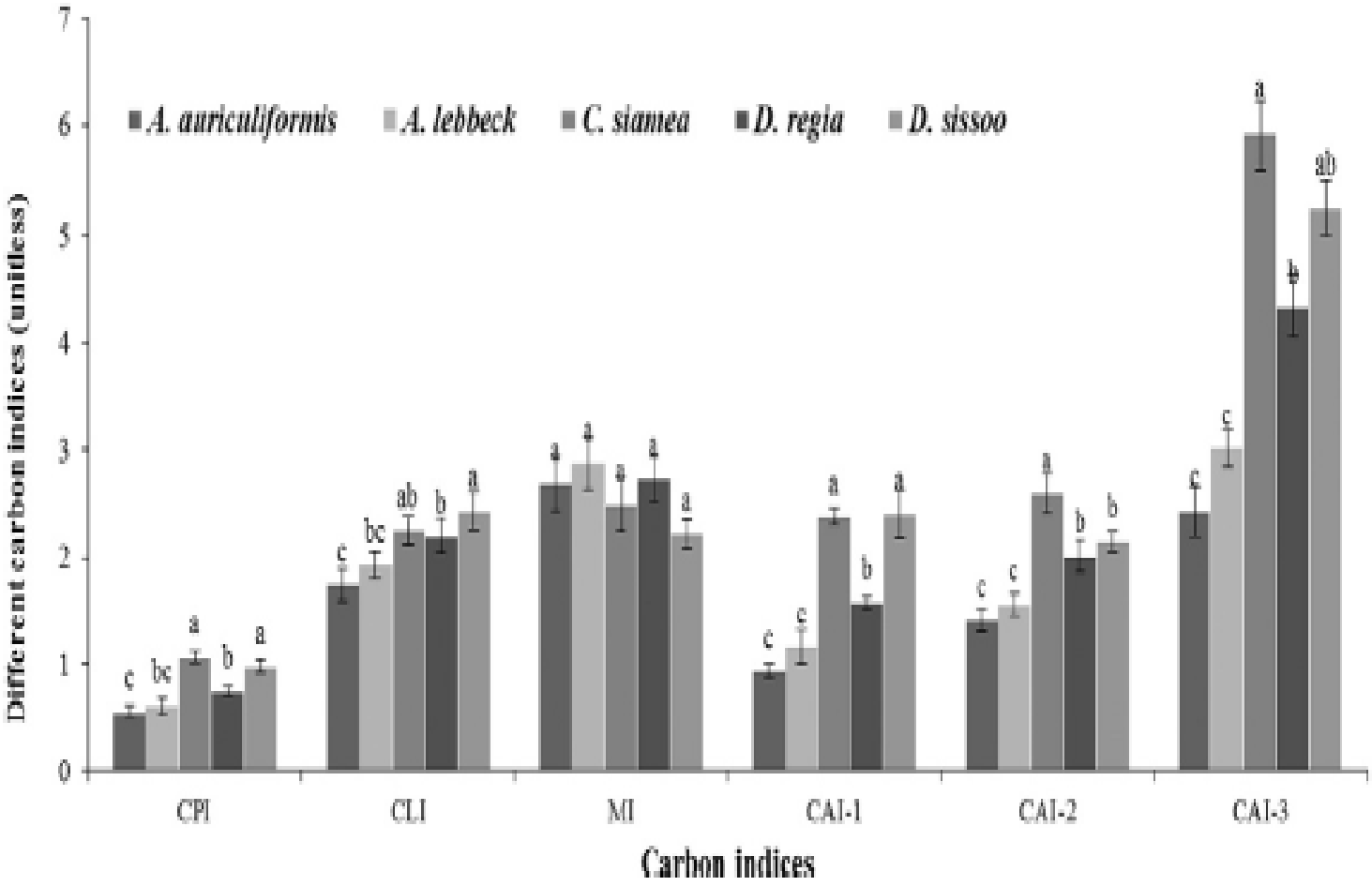


Fig. 1. Carbon indices of different tree species in the reclaimed coalmine sites (error bar, standard deviation; n=10; different letters indicate significant differences at p b 0.05 according to Duncan's multiple range test) (CPI, carbon pool index; LI, lability index; MI, microbial index; CAI, carbon accumulation index). (Adapted from Mukhapadhyay et al. 2016)

Conclusions

- **Both the *quantity* and *quality* of organic material inputs contribute to increased SOM levels.**
- **Most change in SOM occurs in the *active* SOM pool and many soil quality benefits accrue from this pool.**
- **Retention of root-C is higher than that of above-ground residues and hence root/shoot ratios be increased by breeding.**
- **Soil indicators predict the gain or loss of carbon over time and space**

Thanks for Your Attention