Management of Agricultural Soils for Greenhouse Gas Mitigation: Opportunities and Challenges

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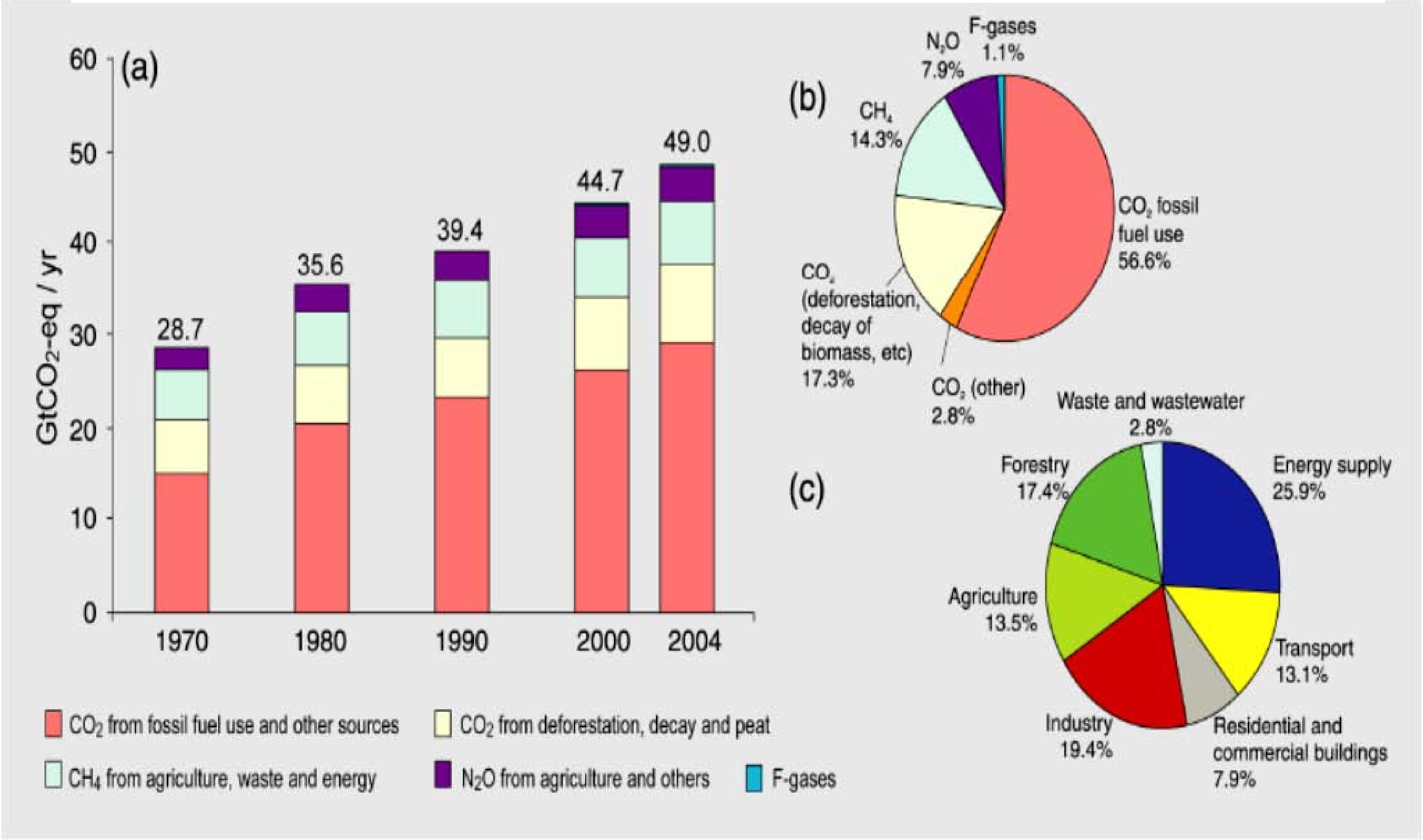
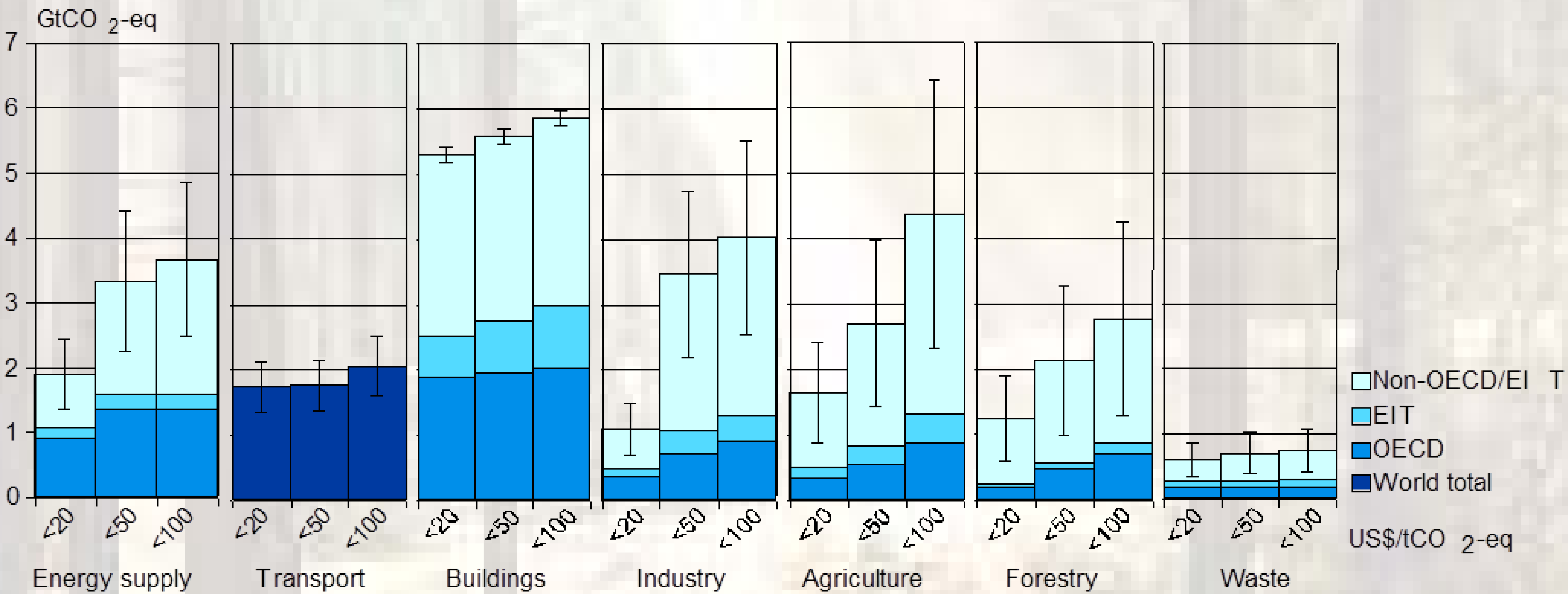
Figure SPM.3. (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation). {Figure 2.1}



Global economic mitigation potential for different sectors at different carbon prices



IPCC, 2007

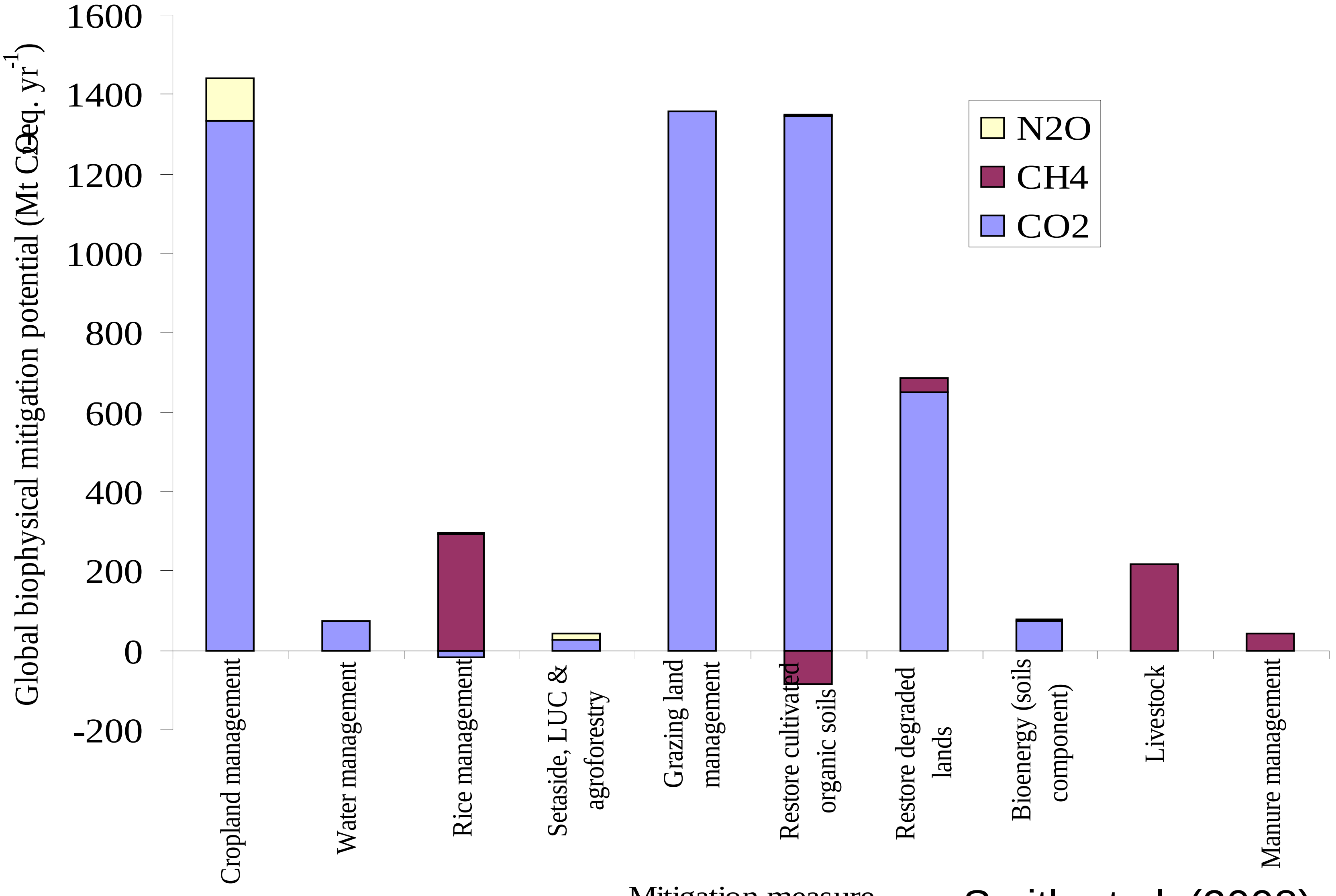
Agriculture

- A large proportion of the mitigation potential of agriculture (excluding bioenergy) arises from soil C sequestration, which has strong synergies with sustainable agriculture and generally reduces vulnerability to climate change.

- Agricultural practices collectively can make a significant contribution at low cost
  - By increasing soil carbon sinks,
  - By reducing GHG emissions,
  - By contributing biomass feedstocks for energy use

IPCC Fourth Assessment Report, Working Group III, 2007

Global mitigation potential in agriculture



Smith et al. (2008)

Agriculture

- **Cropland**
  - Reduced tillage
  - Rotations
  - Cover crops
  - Fertility management
  - Erosion control
  - Irrigation management

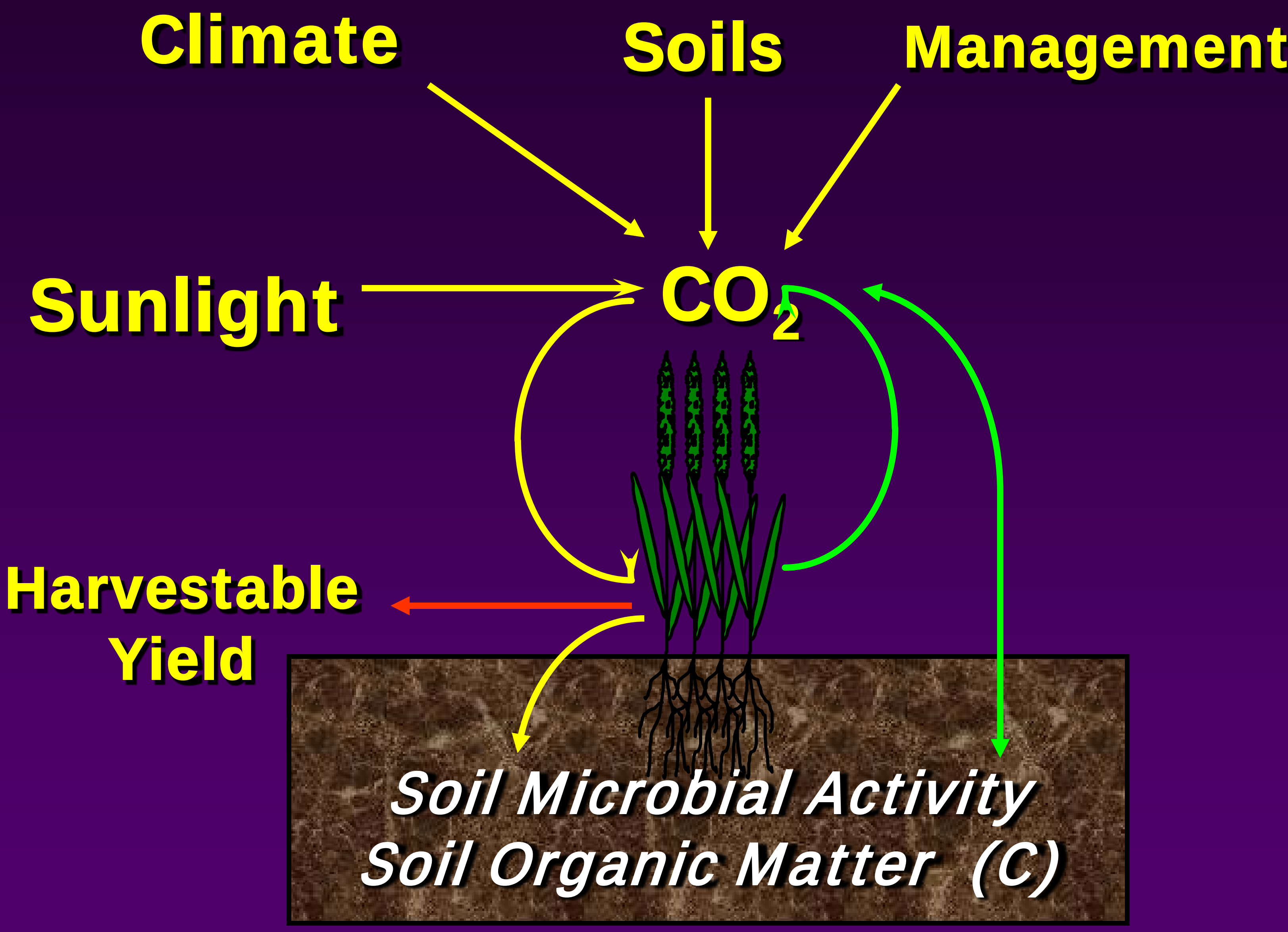
No-till seeding in USA

- **Rice paddies**
  - Irrigation
  - Chemical and organic fertilizer
  - Plant residue management

Rice fields in The Philippines

- **Agroforestry**
  - Improved management of trees and cropland

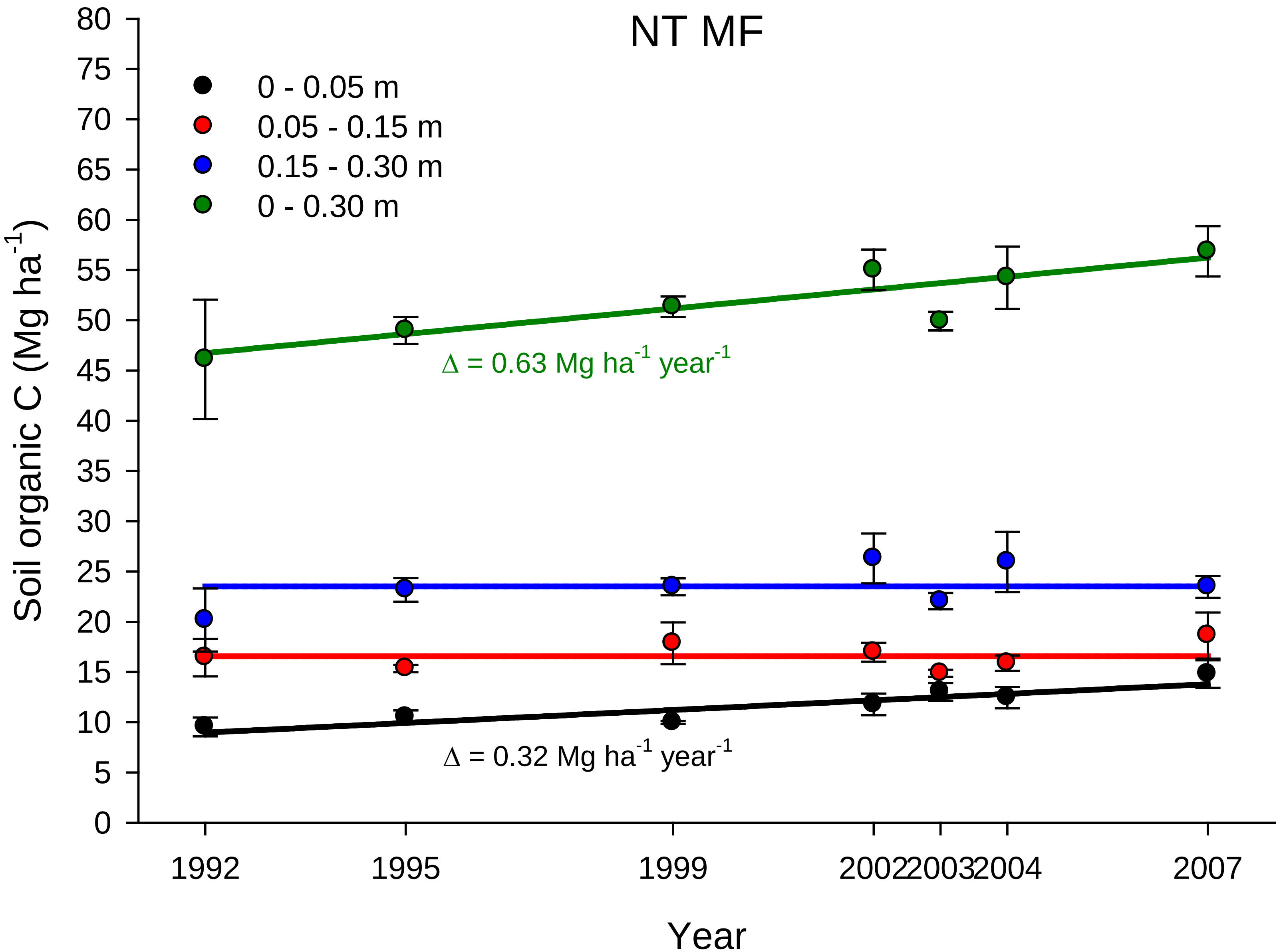
Maize / coffee fields in Mexico


Climate
Soils
Management
Sunlight
CO_2
Harvestable Yield
Soil Microbial Activity
Soil Organic Matter (C)

Biophysical GHG Mitigation Potential

	Soil C
	---- t CO_2e/ha/yr ------
No-till*	**1.09 (-0.26–2.60)**
Winter cover crops*	**0.83 (0.37–3.24)**
Diversify Annual Crop Rotations*	**0.58 (-2.50–3.01)**

Olander et al., 2011


NT MF
0 - 0.05 m
0.05 - 0.15 m
0.15 - 0.30 m
0 - 0.30 m
Δ = 0.63 Mg ha-1 year-1
Δ = 0.32 Mg ha-1 year-1
Soil organic C (Mg ha-1)
Year
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
1992
1995
1999
2002
2003
2004
2007

Latitude	Mean Temp	Mean Precip	Drainage Class	Crop	Time	Depth	ΔSOC
	ºC	mm			years	cm	Mg ha^{-1} yr^{-1}
46ºN	6	1000	well drained	soybean-barley	16	60	- 0.20
41ºN	10	920	poorly drained	corn-soybean	15	60	-1.58
41ºN	9	1000	s. poorly drained	corn-soybean	8	60	-0.98
40ºN	10	960	well drained	corn-soybean	30	60	1.21
41ºN	8	1070	m. well drained	corn-soybean	10	60	1.60
39ºN	11	800	m. well drained	corn	17	90	0.61
28ºS	19	1730	well drained	soybean-wheat-soybean-oat	22	90	0.42

No-Tillage Cropping Systems
Conservation Agriculture

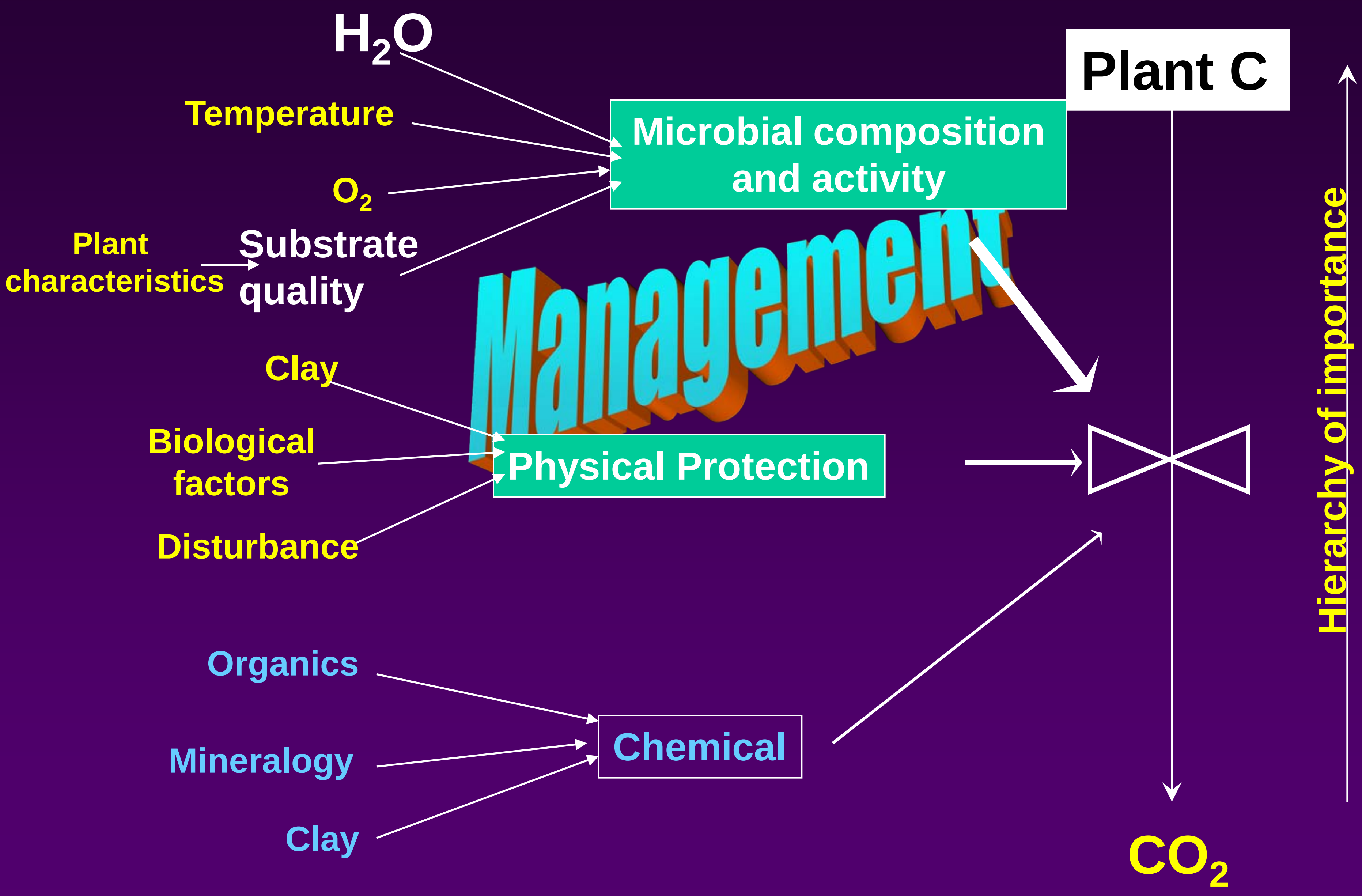
- Restores soil carbon
- Conserves moisture
- Saves fuel
- Saves labor
- Lowers machinery costs
- Reduces erosion
- Improved soil fertility
- Controls weed
- Planting on the best date
- Improves wildlife habitat

Carbon sequestration rate (C rate) expressed in equivalent mass (Mg C/ha/y) to a 30 cm depth for Manhattan, KS USA
Conversion from tilled to no-till

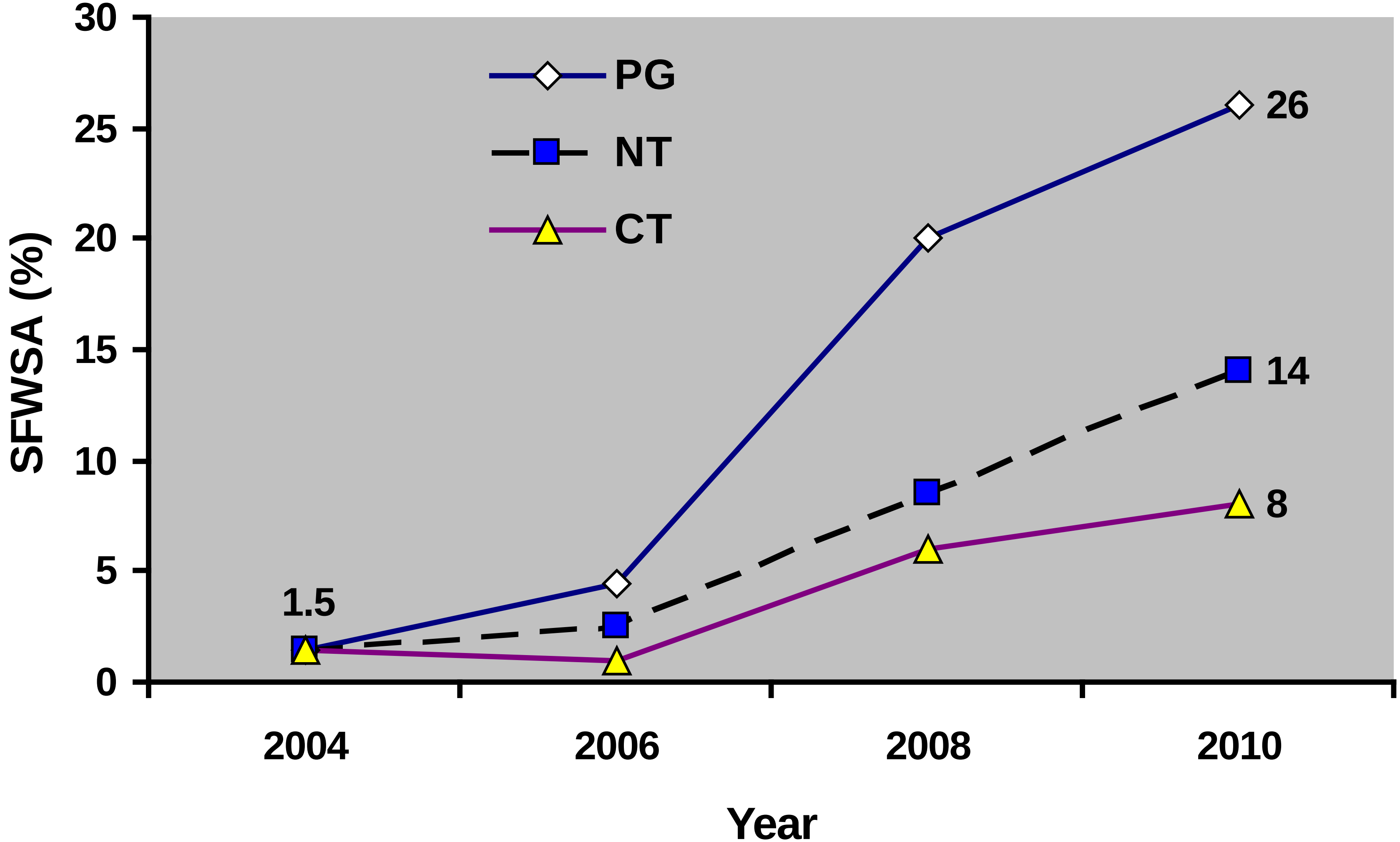
Rotation	
Continuous Soybean	0.066
Continuous Sorghum	0.292
Continuous Wheat	0.487
Soybean - Wheat	0.510
Soybean - Sorghum	0.311

Fabrizzi, 2006

Conservation of Soil Carbon

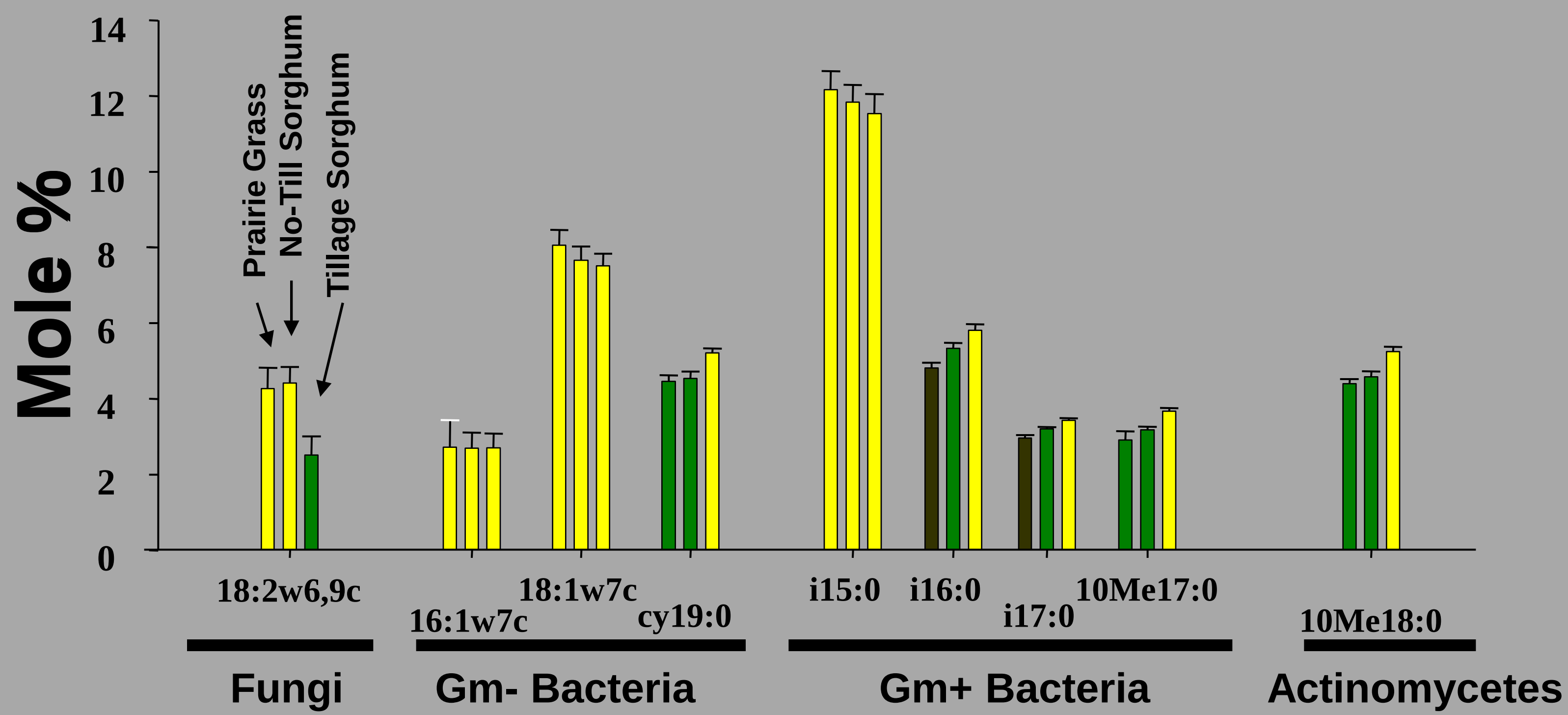


Change in macroaggregate (>2000 um) over time



PG: prairie grass (big bluestem); NT: No-till sorghum; CT: Conventional till sorghum.
SFWSA: sand-free water stable aggregate

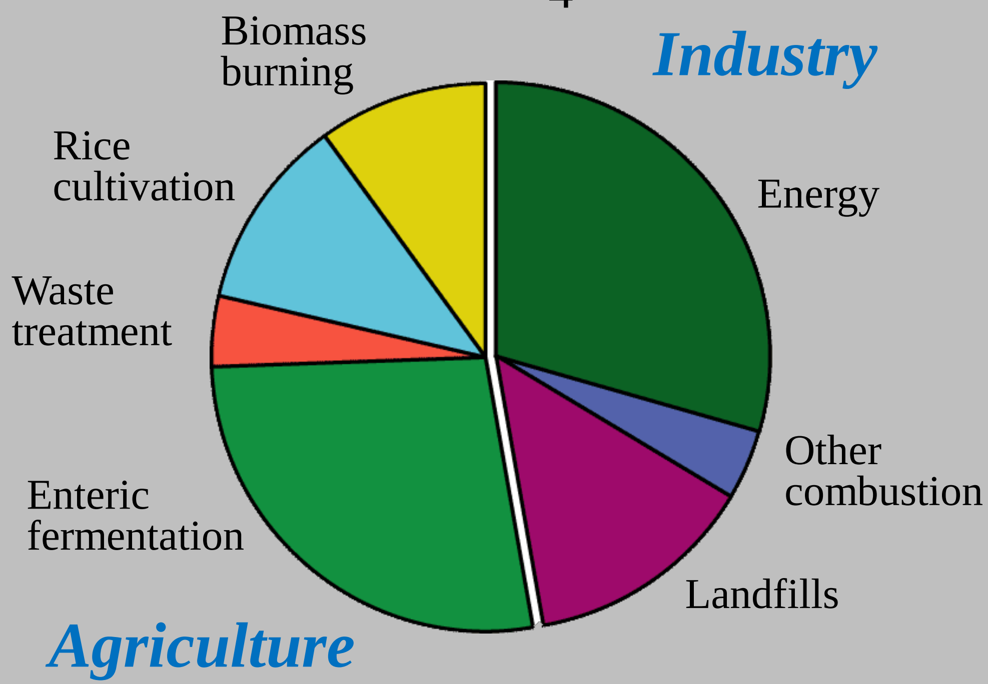
Soil PLFA 2006 (0-5 cm)



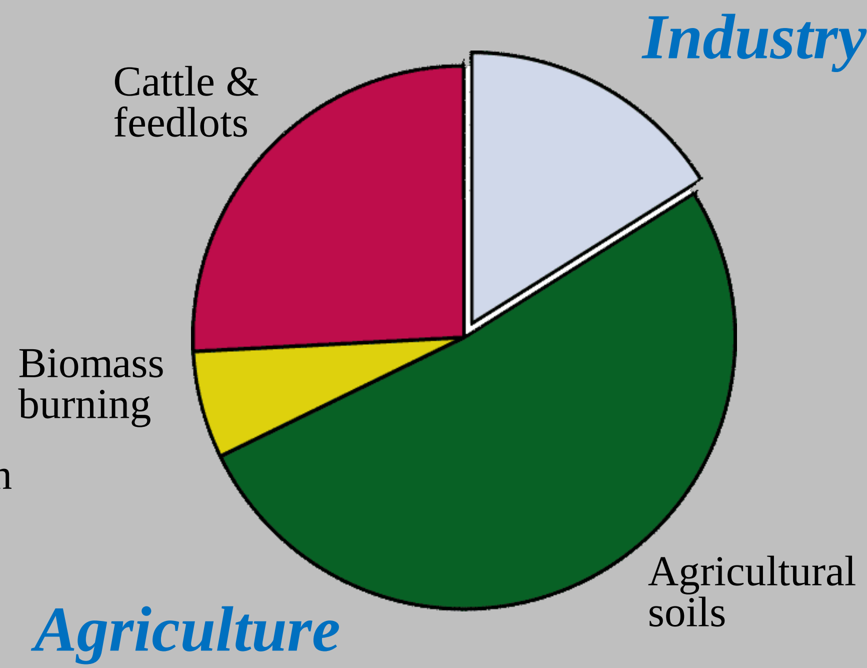
After 3 yrs higher amounts of saprophytic fungi, and lower amounts of bacteria were characteristic of the less disturbed PG and NT, compared to tilled CT.

Anthropic Sources of Methane and Nitrous Oxide Globally

CH_4



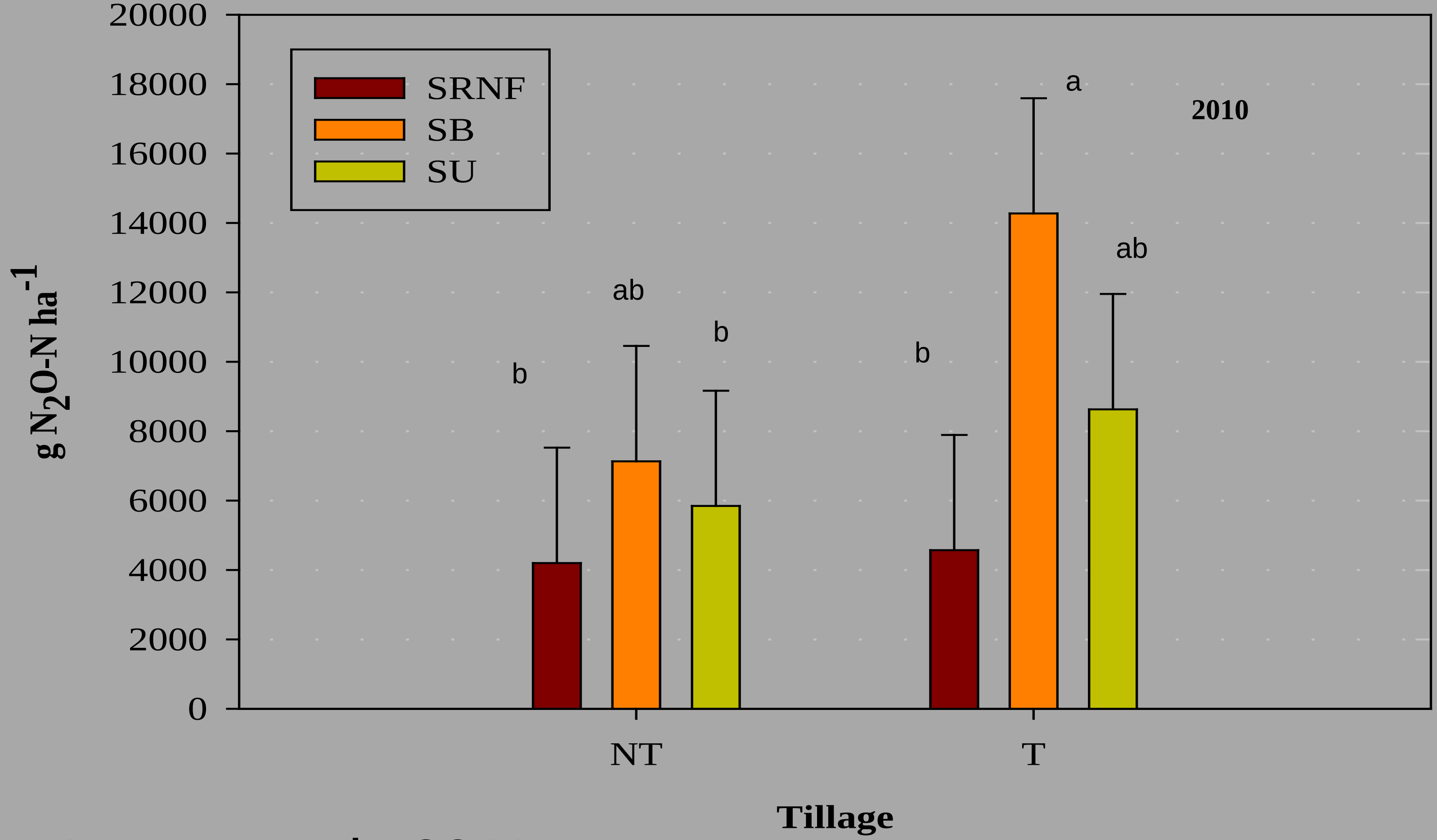
N_2O



Total Impact 2.0 Pg C_{equiv} 1.2 Pg C_{equiv}

Source IPCC 2001; from Robertson 2004

Long-Term Exp: Cumulative N_2O-N emissions



Arango et al., 2011

N_2O Mitigation Potentials

Practice	% Reduction
Soil Emissions	
Soil N Tests	10
Fertilizer Timing	10
Cover Crops	5
N Fertilizer Placement	5
Nitrification & Urease Inhibitors	5
Indirect Fluxes	
Crop N use efficiency	20
Riparian Zone Management	5
Ammonia Management	5
Wastewater Treatment	5

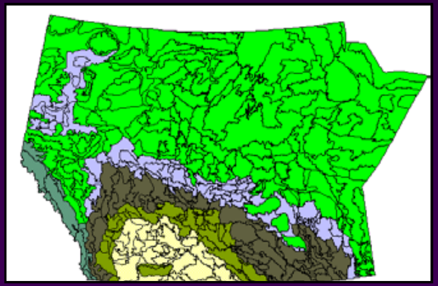
Robertson

Barriers

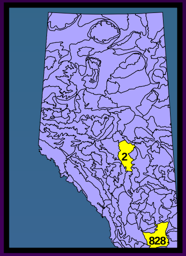
Upscaling from sites to regions across time

Time arrow

Databases, remote observations

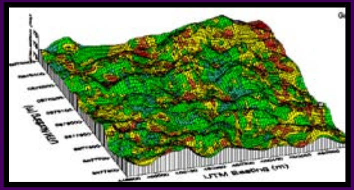


10^{12} m^2



10^{9} m^2

Experiments



10^{6} m^2

10^{3} m^2

10^{1} m^2

10^{-6} m^2

Simpler models, metamodels?

Process models, landscape models

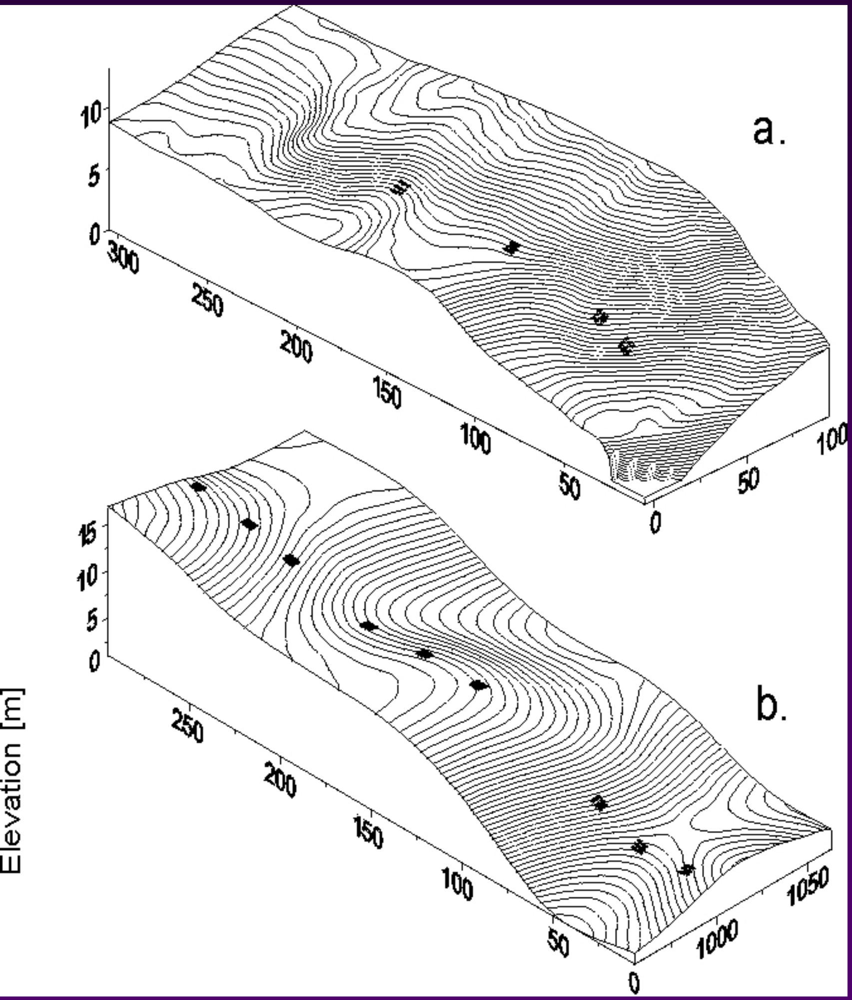
Measurement, Monitoring and Verification

- Detecting soil C changes
  - Difficult on short time scales
  - Amount of change small compared to total C

- Methods for detecting and projecting soil C changes (Post et al. 2001)
  - Direct methods
    - Field measurements
  - Indirect methods
    - Accounting
      - Stratified accounting
      - Remote sensing
      - Models

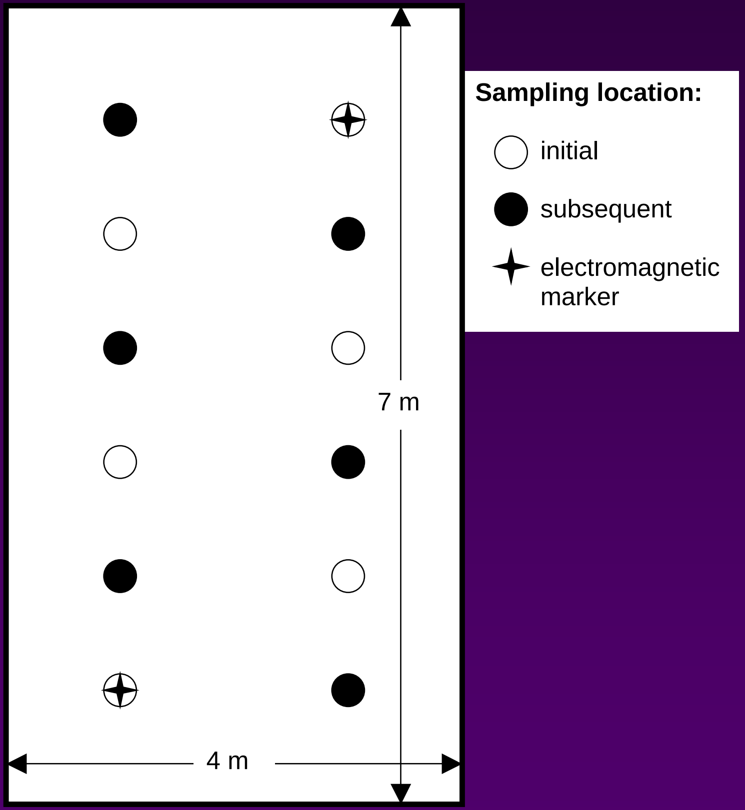
Post et al. (2001)

Sampling strategies: account for variable landscapes



Geo-reference microsites

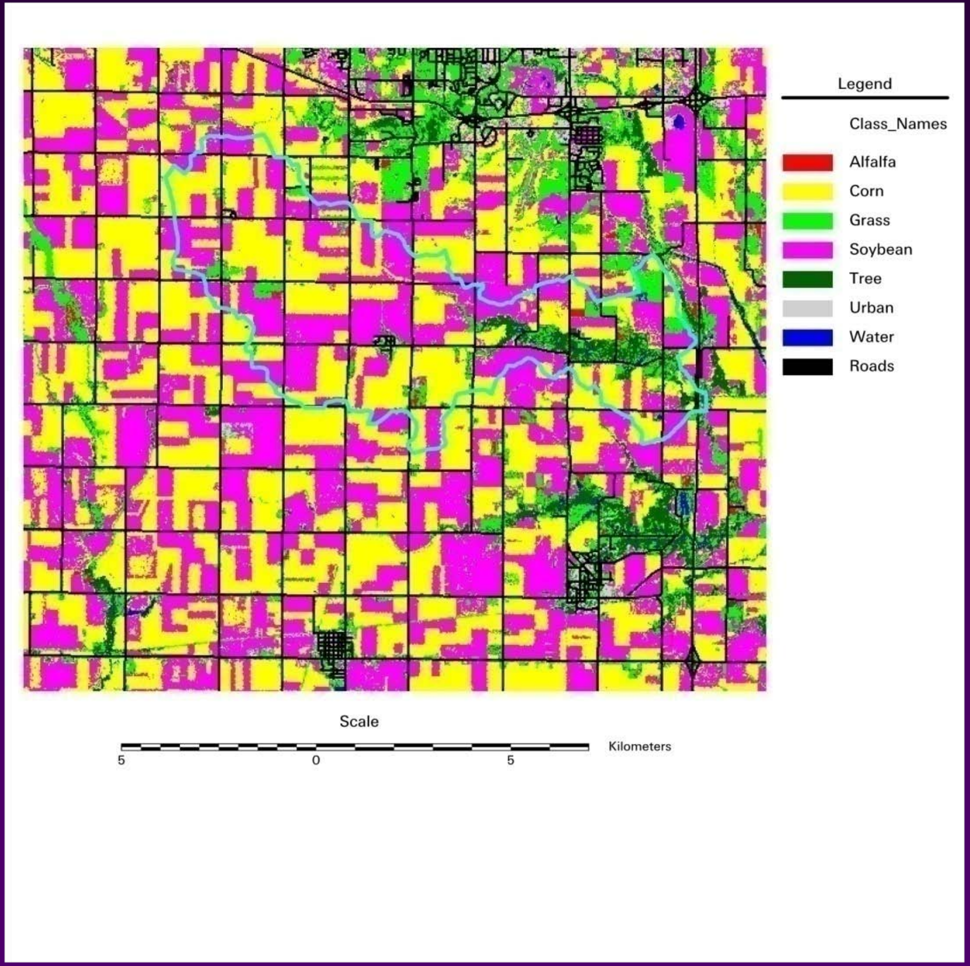
- Microsites reduces spatial variability
- Simple and inexpensive
- Used to improve models
- Used to adopt new technology
- Soil C changes detected in 3 yr
  - 0.71 Mg C ha^{-1} – semiarid
  - 1.25 Mg C ha^{-1} – subhumid



Ellert et al. (2001)

Remote Sensing and Carbon Sequestration and GHG Reductions

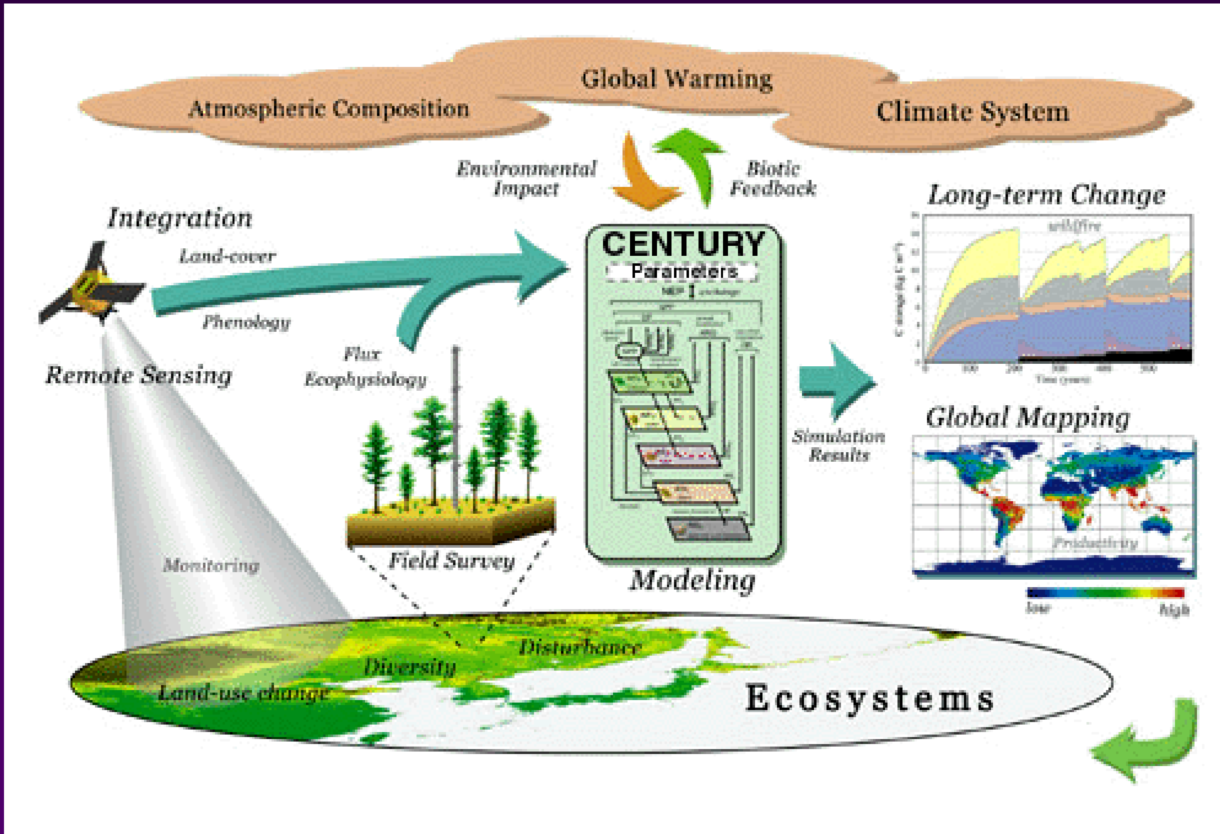
- Remote sensing cannot be used to measure soil C directly unless soil is bare.
- Remote sensing useful for assessing:
  - Vegetation
    - Type
    - Cover
    - Productivity
  - Water, soil temperature
  - Tillage intensity?



Crop identification for spatial modeling. Courtesy: P Doraiswamy, USDA-ARS, Beltsville, MD

Methods to Extrapolate Measurements and Model Predictions from Sites to Regional Scales

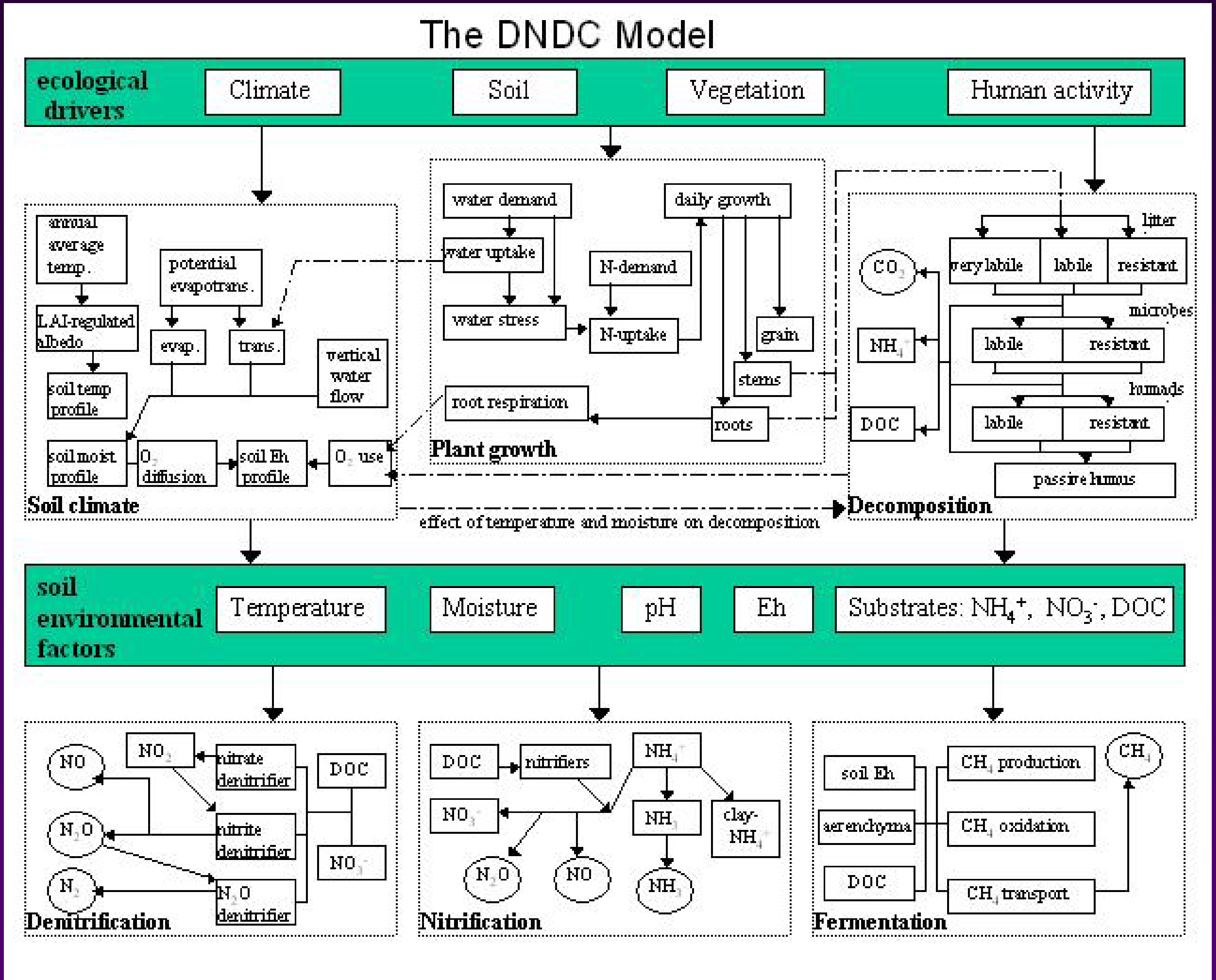
- Models
  - CENTURY
    - Comet VR
  - EPIC
  - RothC
  - Other models also being developed



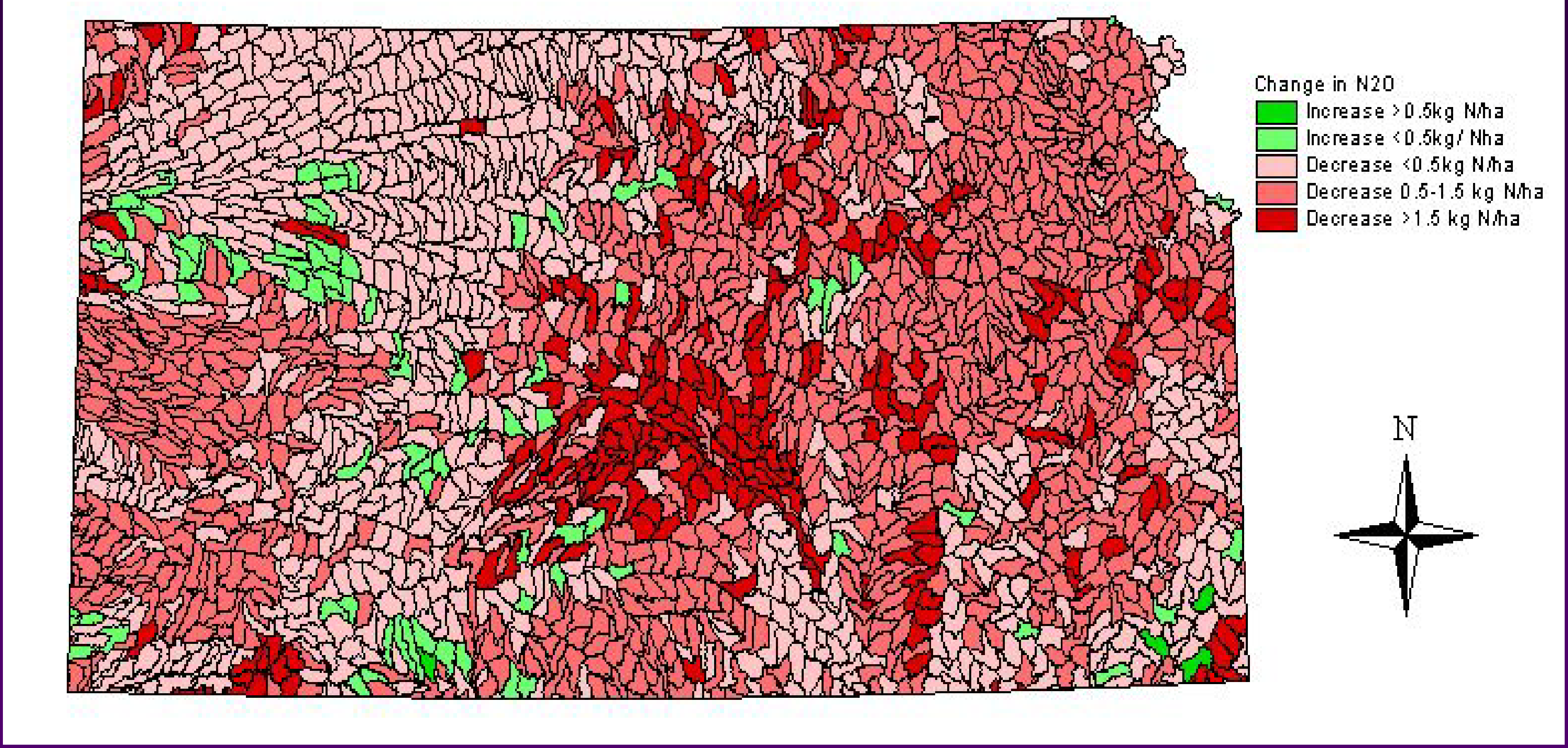
CENTURY MODEL

http://www.cometvr.colostate.edu/images/ecosystem.gif

Modeling


The DNDC Model
ecological drivers
Climate
Soil
Vegetation
Human activity
annual average temp.
LAI-regulated albedo
soil temp profile
soil moist profile
potential evapotrans.
evap.
trans.
vertical water flow
O2 diffusion
soil Eh profile
O2 use
Soil climate
water demand
water uptake
water stress
N-demand
N-uptake
daily growth
grain
stems
roots
root respiration
Plant growth
litter
very labile
labile
resistant
microbes
labile
resistant
humads
labile
resistant
passive humus
CO2
NH4+
DOC
Decomposition
effect of temperature and moisture on decomposition
soil environmental factors
Temperature
Moisture
pH
Eh
Substrates: NH4+, NO3-, DOC
NO
N2O
N2
NO2
nitrate denitrifier
nitrite denitrifier
N2O denitrifier
DOC
NO3-
Denitrification
DOC
nitrifiers
NO3-
NH4+
NH3
clay-NH4+
N2O
NO
NH3
Nitrification
soil Eh
aerenchyma
DOC
CH4 production
CH4 oxidation
CH4 transport
CH4
Fermentation

N2O Emission Rates: Conventional vs No-till (Irrigated corn)



Monitoring and Verification

Level	Resolution	Cost	Producer Acceptance
Practiced Based			
Individual Fields			

Mitigation Opportunities for Agriculture

- Offsets
  - Soil Carbon
    - Cropping systems: No-tillage, rotations
    - Grasslands
    - Rangelands
  - Nitrous oxide reductions from improved N use efficiency
- Fuel reductions
- Energy efficiency

Conclusions: Mitigation

- Agriculture has a significant role to play in climate mitigation
- Agriculture is cost competitive with mitigation options in other sectors
- Many mitigation options improve sustainability

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