UNIVERSITY OF ABERDEEN

Impacts of Climate Change on Agroecosystems

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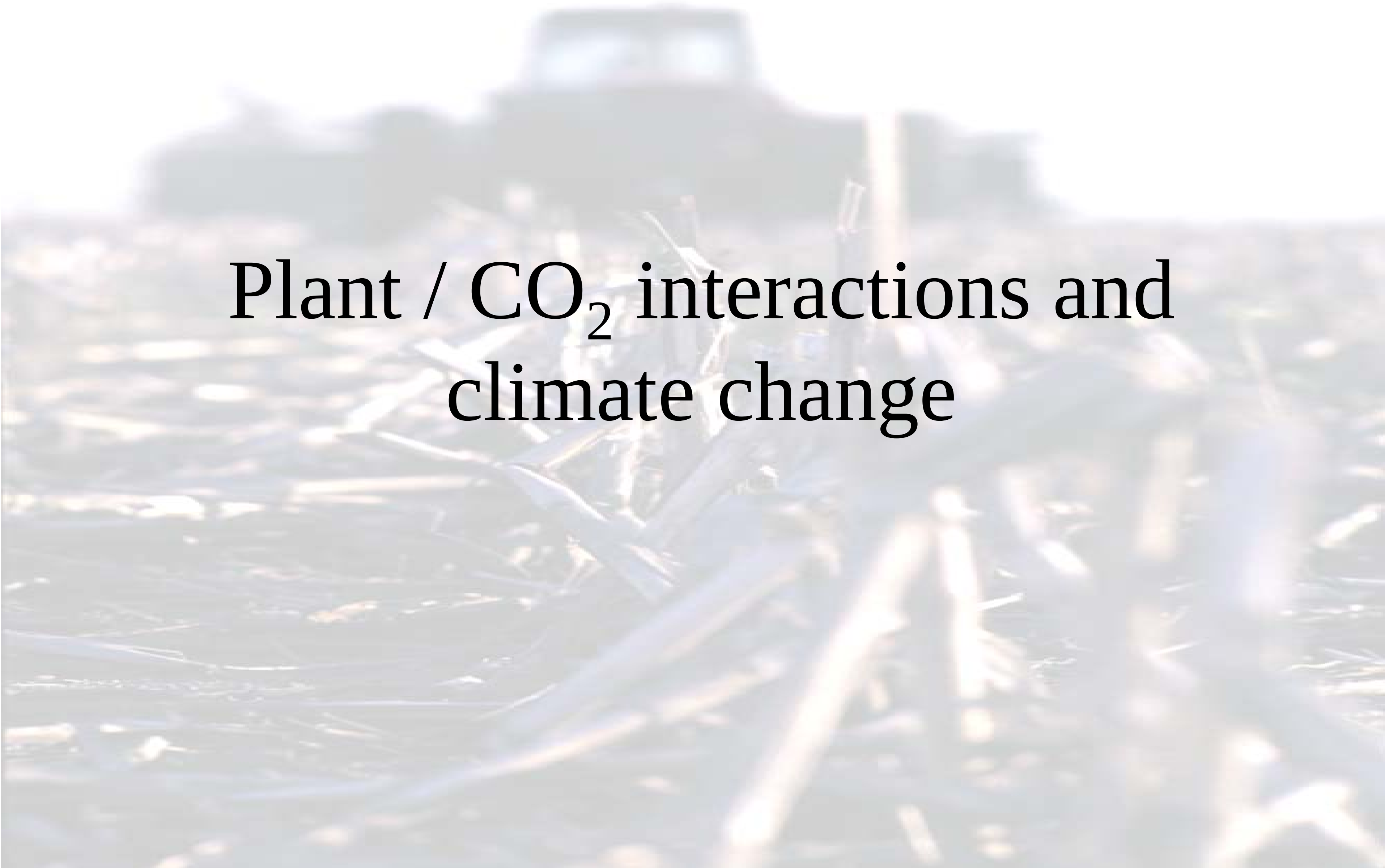
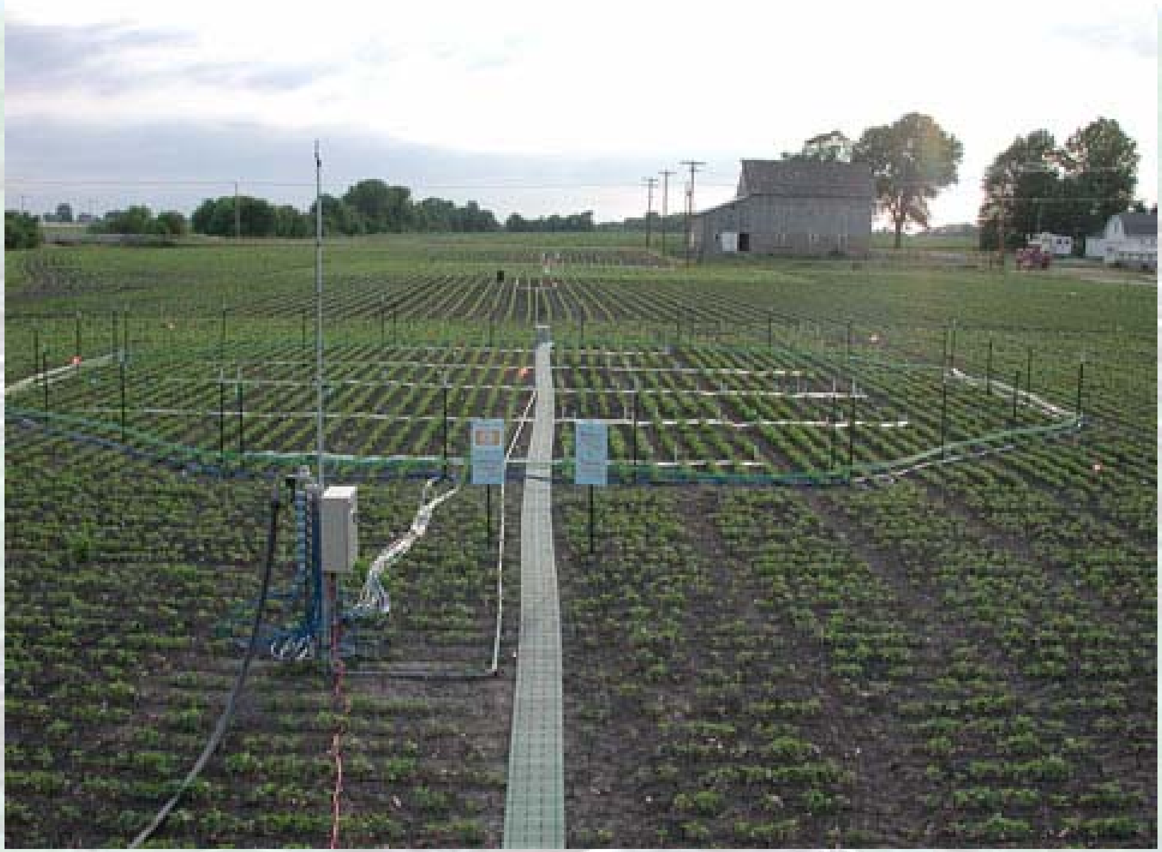
Overview

- Climate change impacts on crops
- Climate change impacts on whole agroecosystems
- Management to mitigate climate change
- Global significance of the European cropland C sequestration potential
- Vulnerability

Plant / CO_2 interactions and climate change

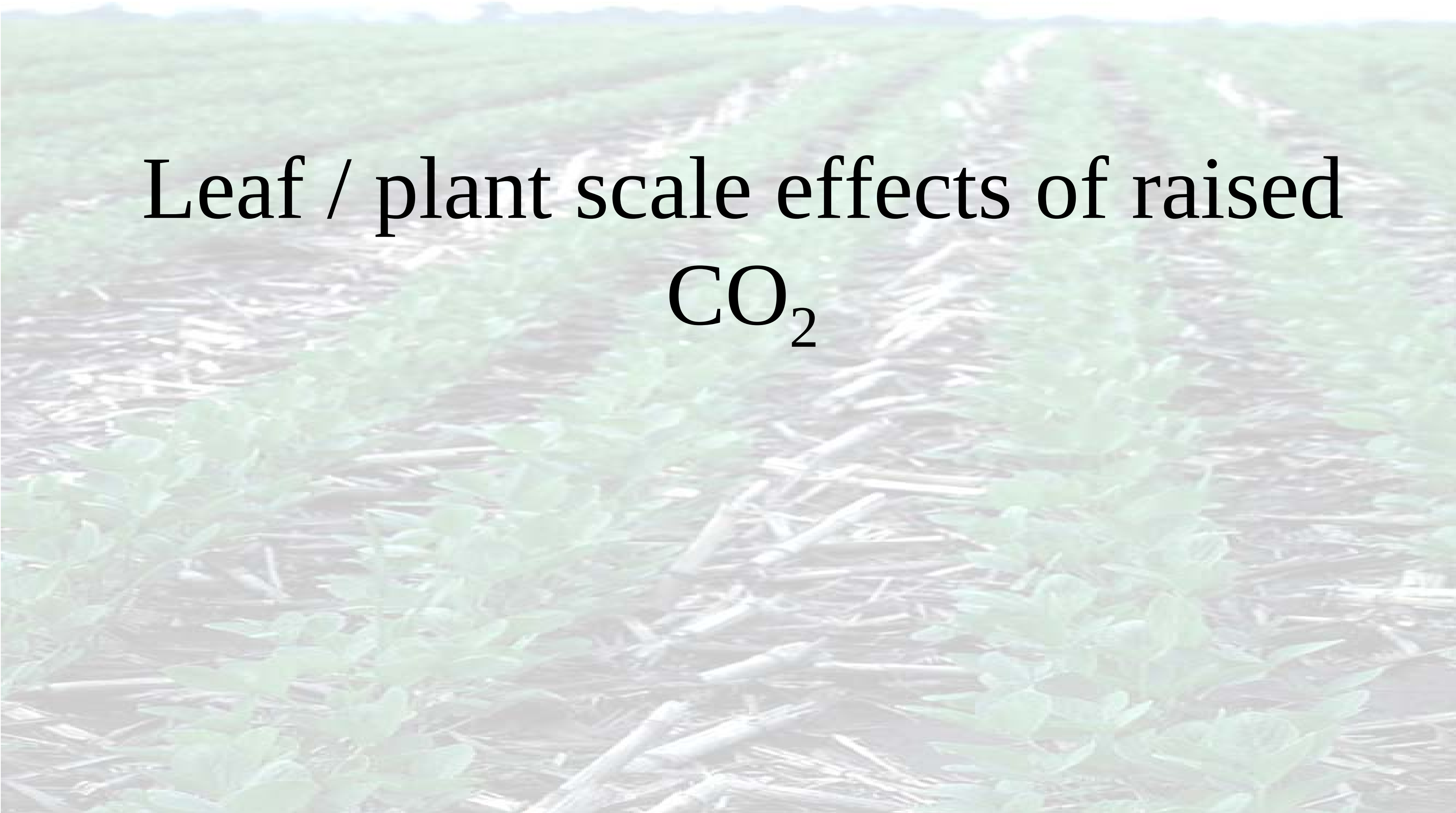


FACE experiments



SoyFACE experiment

Leaf / plant scale effects of raised CO_2



Process-level effects of raised CO_2

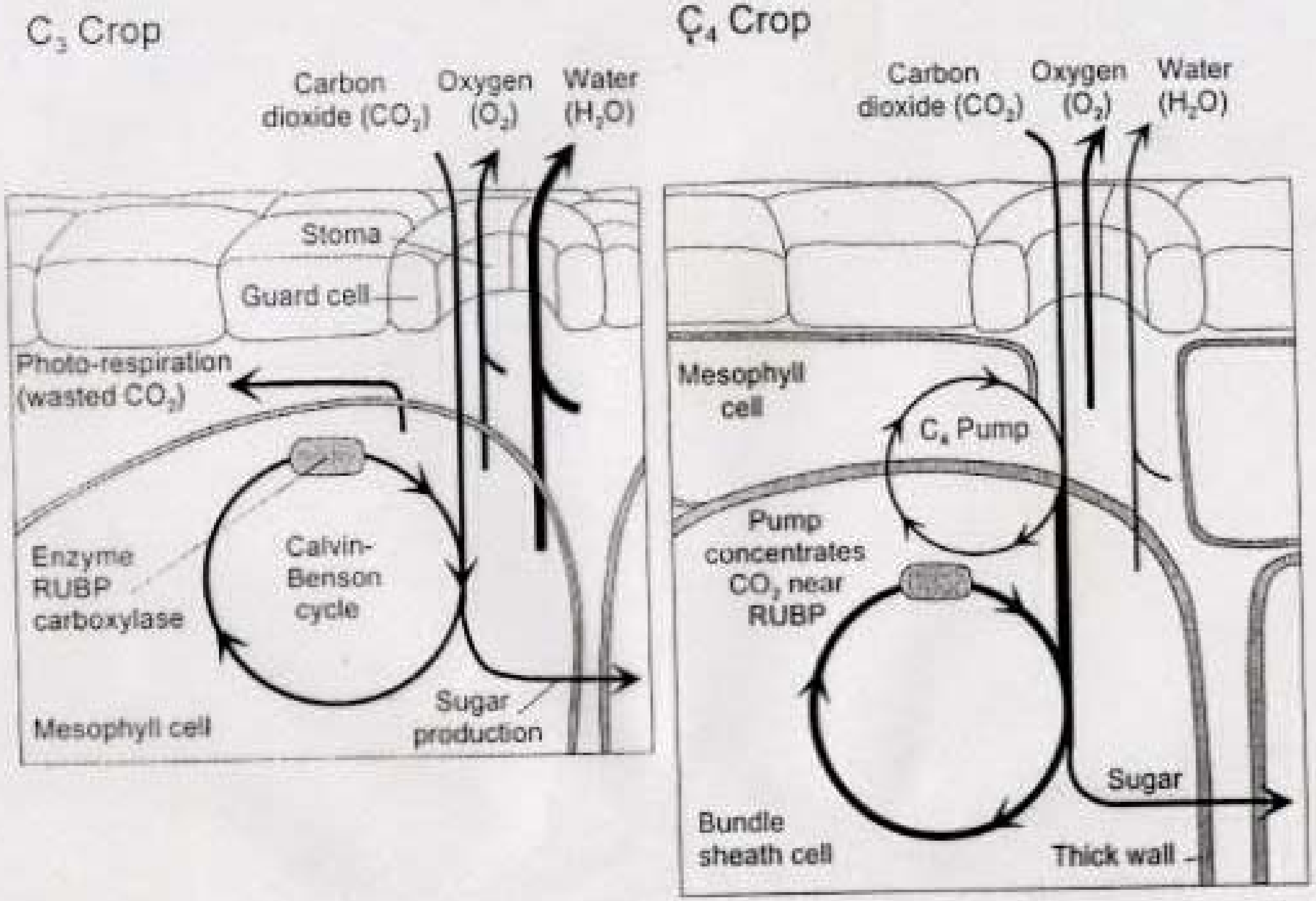


Figure 3.2 Biochemical pathways of photosynthetic CO_2 fixation (redrawn from Bazzaz and Fajer, 1992).

Leaf / plant scale effects - photosynthesis

- Overwhelming evidence that increased CO_2 leads to increased photosynthesis (Drake et al., 1997)
- C_3 and C_4 plants respond differently – C_3 plants more than C_4 plants (Akita & Moss, 1973)
- Some acclimation occurs in the long run (Cure & Acock, 1986)

Leaf / plant scale effects - WUE

- Overwhelming evidence that elevated CO_2 reduces stomatal conductance (Drake et al., 1997)
- Decreased transpiration and much greater (70-100%) WUE
- Effect less pronounced at the canopy level (Rosenzweig & Hillel, 1998)

Canopy / community scale effects of raised CO_2

Canopy / community scale effects - WUE

- Effect of raised CO_2 on WUE much less pronounced at the canopy level (Rosenzweig & Hillel, 1998)

Canopy / community scale effects 2

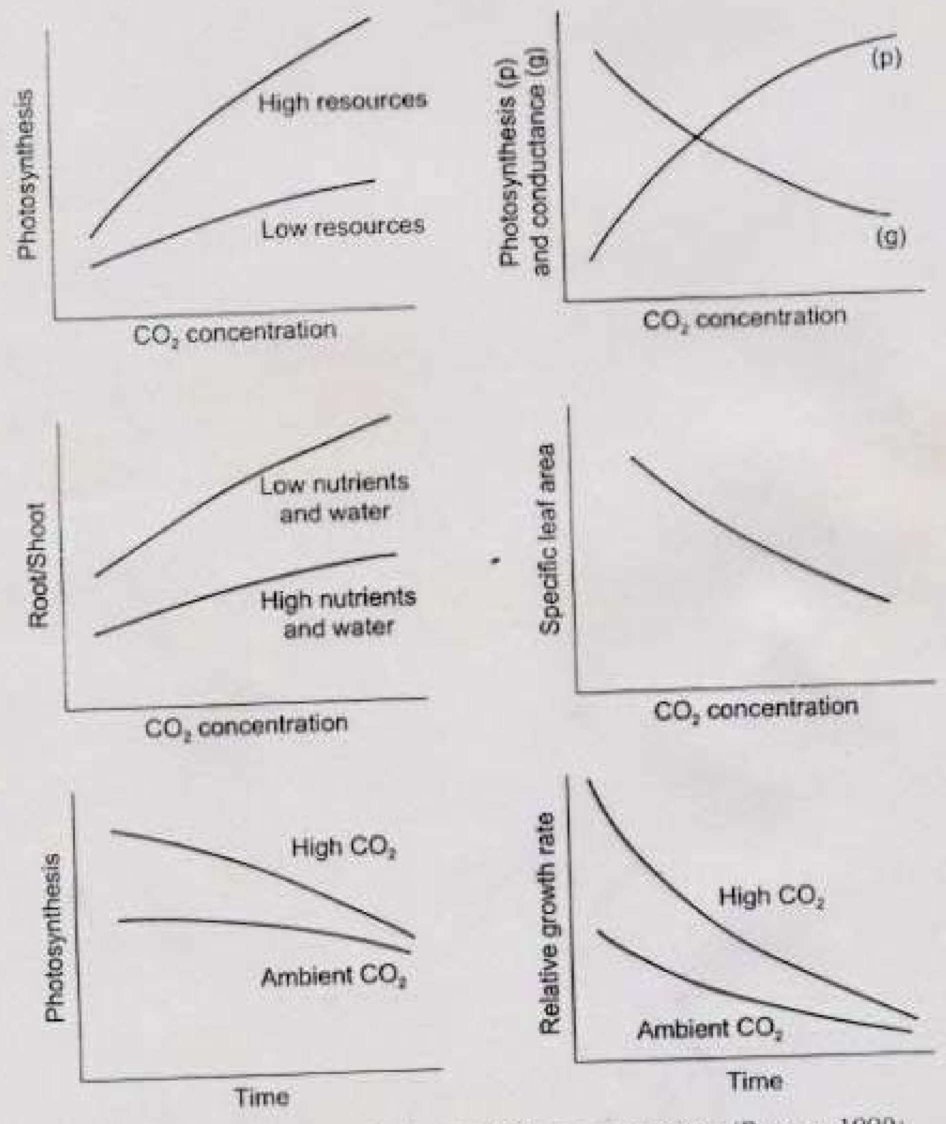
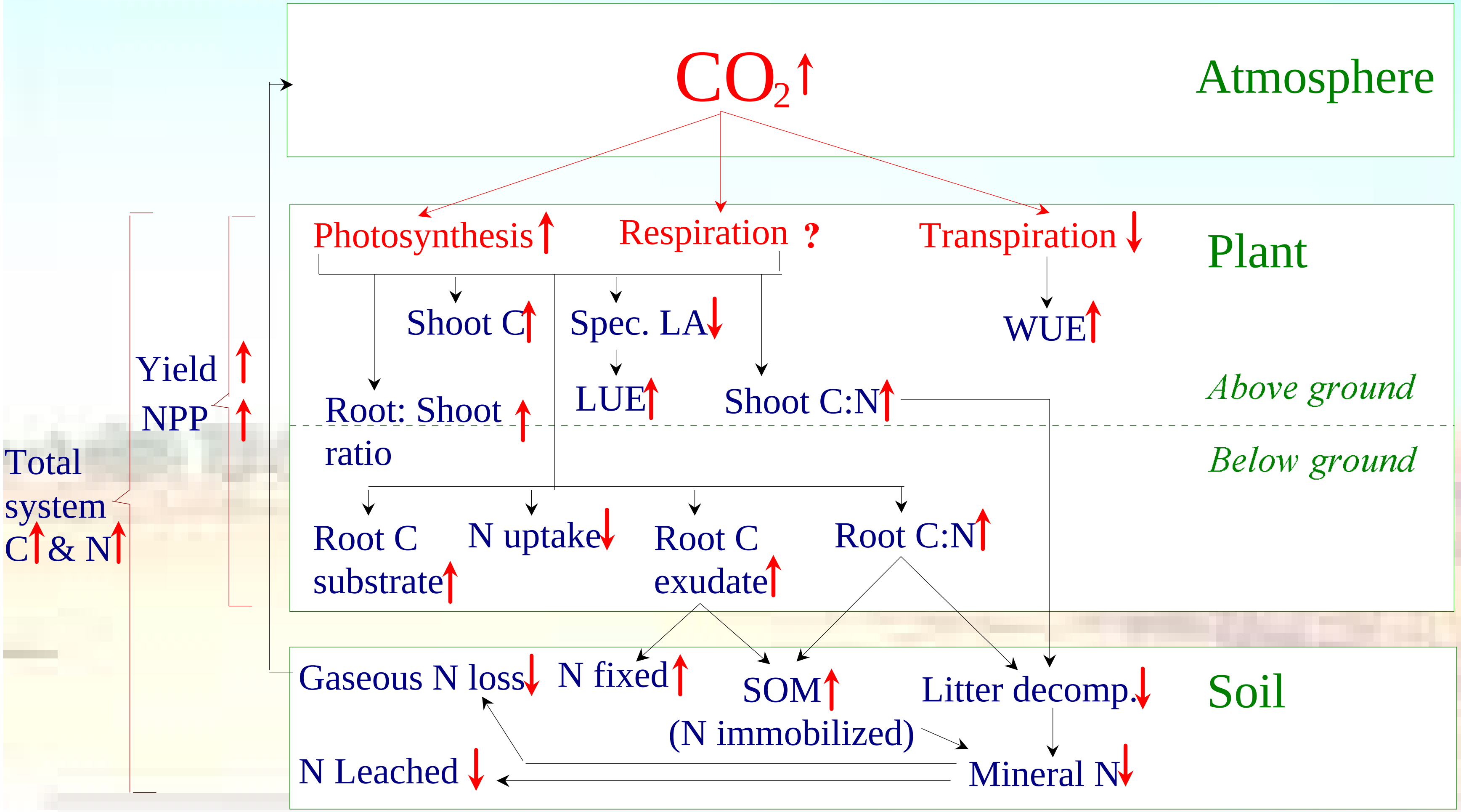


Figure 3.1 Responses of plants to CO_2 concentration (Bazzaz, 1990).

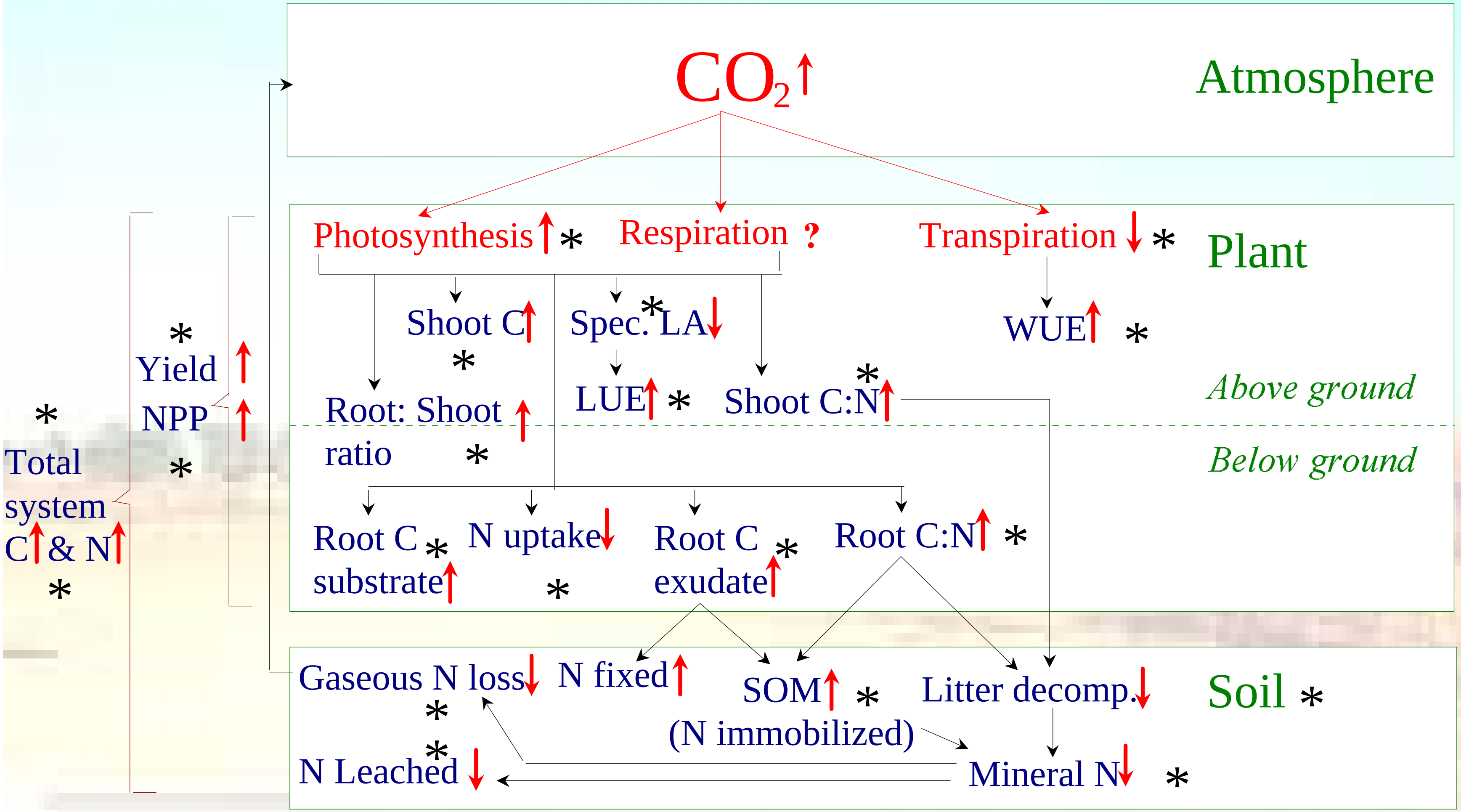
Climate change impacts on whole agroecosystems

Ecosystem level impacts of raised CO_2



Smith *et al.*, 2000

Ecosystem level impacts of raised CO_2 - interactions



* = N has an impact

Ecosystem level plant / CO_2 interactions

- Complex
- Many feedbacks
- Difficult to predict
- Some impacts may be species / ecosystem specific

Temperature and rainfall

- Temperature - increase will increase production
- Rainfall - increase could increase production; decrease could seriously reduce production
- Southern Europe - serious water shortages, competition for water resources for irrigation, cropping vulnerable

Combined impacts - Temperature, rainfall and CO_2 (Olesen, 2003) - 1

- Climatic warming and associated increase in atmospheric CO_2 concentration will increase the productivity of agricultural crops.
- Some evidence that grass and other fodder crops may benefit more than cereals
- Full benefits of the climatic warming requires adaptation in crop management, i.e. later sowings for winter cereals and earlier sowings for spring cereals.

Combined impacts - Temperature, rainfall and CO_2 (Olesen, 2003) - 2

- Some crop substitution will probably occur. On dairy farms more cereals will be grown due to higher productivity of the grasslands, which frees up some land for grain production.
- On sandy loam and loam soils spring cereals may become slightly more favorable and winter cereals slightly less favorable.

Management to mitigate climate change

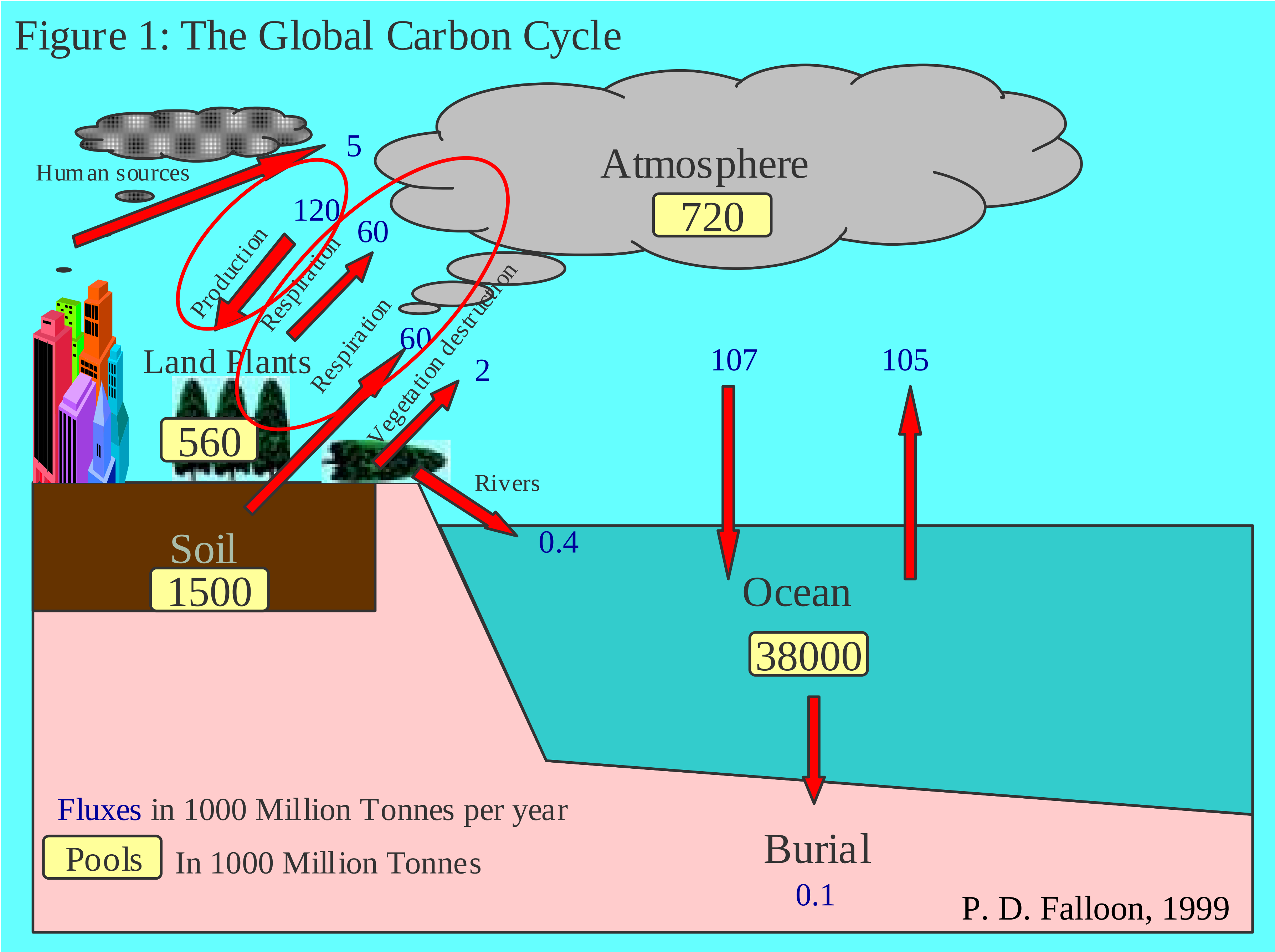


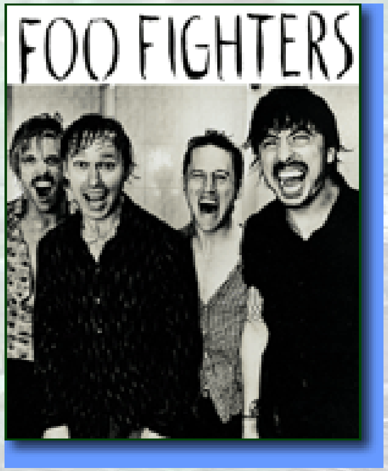
Figure 1: The Global Carbon Cycle
Human sources
5
120
Production
Respiration
60
Respiration
60
Vegetation destruction
2
Atmosphere
720
Land Plants
560
Soil
1500
Rivers
0.4
107
105
Ocean
38000
Burial
0.1
Fluxes in 1000 Million Tonnes per year
Pools
In 1000 Million Tonnes
P. D. Falloon, 1999

Carbon sinks

- Kyoto Article 3.3 - Afforestation, Deforestation, Reforestation
- Kyoto Article 3.4 - see below

Afforestation

- Already captured public imagination
- Foo Fighters - forest planted to replace CO_2 emitted in production and distribution of their latest CD
- Planted by FutreForests (www.futureforests.com)
- Also: Coldplay, David Gray, Massive Attack, Mel C, Atomic Kitten



Kyoto Protocol Article 3.4 activities

- Forestry management
- Cropland management
- Grazing land management
- Re-vegetation

NORTH AMERICA

US farmers are being paid to shift from ploughing to reduced cultivations in a novel carbon credits deal with Canadian power companies.

US growers rest ploughs to earn carbon credits

By Stephen Leahy

CANADA'S biggest power companies are paying farmers in Iowa £8-16/ha (US$5-10/acre) to park their ploughs this spring.

This is not altruistic concern over soil conservation, but part of a hard-nosed trade in the world's newest commodity — carbon credits.

For farmers in Iowa it is manna from a northern heaven. "It's a good source of income for doing nothing. It's a gift," says Roger Doescher who farms 100ha (250 acres) of maize and soybean in New Hartford.

CARBON CREDITS

- No-till cuts CO_2 release.
- Power companies buy credits to offset enviro obligations.
- Worth £8-16/ha.
- 400 mid-west US farmers.

Ploughing farmland causes oxidation of organic matter which releases carbon dioxide at a rate of 0.6-10t/ha (0.25-4t/acre) annually. Carbon dioxide is the main cause of global warming and reducing emissions of this greenhouse gas is the focus of the international Kyoto Agreement.

By paying 400 farmers in the mid-west of the US to no-till their land, Canadian utilities are reducing their carbon dioxide emissions by as much as 2.8m tonnes. The resulting 'carbon credit' can then be used to offset their legal obligation to cut emissions.

Frank Lewis of West Des Moines, Iowa, owns several large corn/soybean farms and signed on to enhance his return in a time of low commodity prices. New no-till equipment will be needed, Mr Lewis says. But costs will be offset by the payments, reduced inputs from no-till, soil conservation benefits and improved wildlife habitat.

Carbon credits should increase in value over time, which should attract other farmers, he believes. "Carbon credits have the potential to dramatically increase the numbers of no-till acres."

The program, run and sold by crop insurer IGF Insurance of Des Moines, also gives farmers advance payments to help with equipment purchases. Independent evaluation and verification is done on each farm to estimate the carbon savings and future payments will be made on that basis.

The credits are a simple and low-cost way for industry to reduce greenhouse emissions says Steve Griffin of IGF.

Farmers can also sell credits for burning less fuel and reducing nitrogen applications — nitrogen oxide is another greenhouse gas. Additional credits can be secured by planting trees and grass buffer strips, idling acres, biomass power generation and methane abatement from livestock waste.

"Most farmers have no idea that tillage puts carbon dioxide into the atmosphere," says Mr Doescher a long-time advocate of no-till. "Many farmers will be in favour once they understand." ■

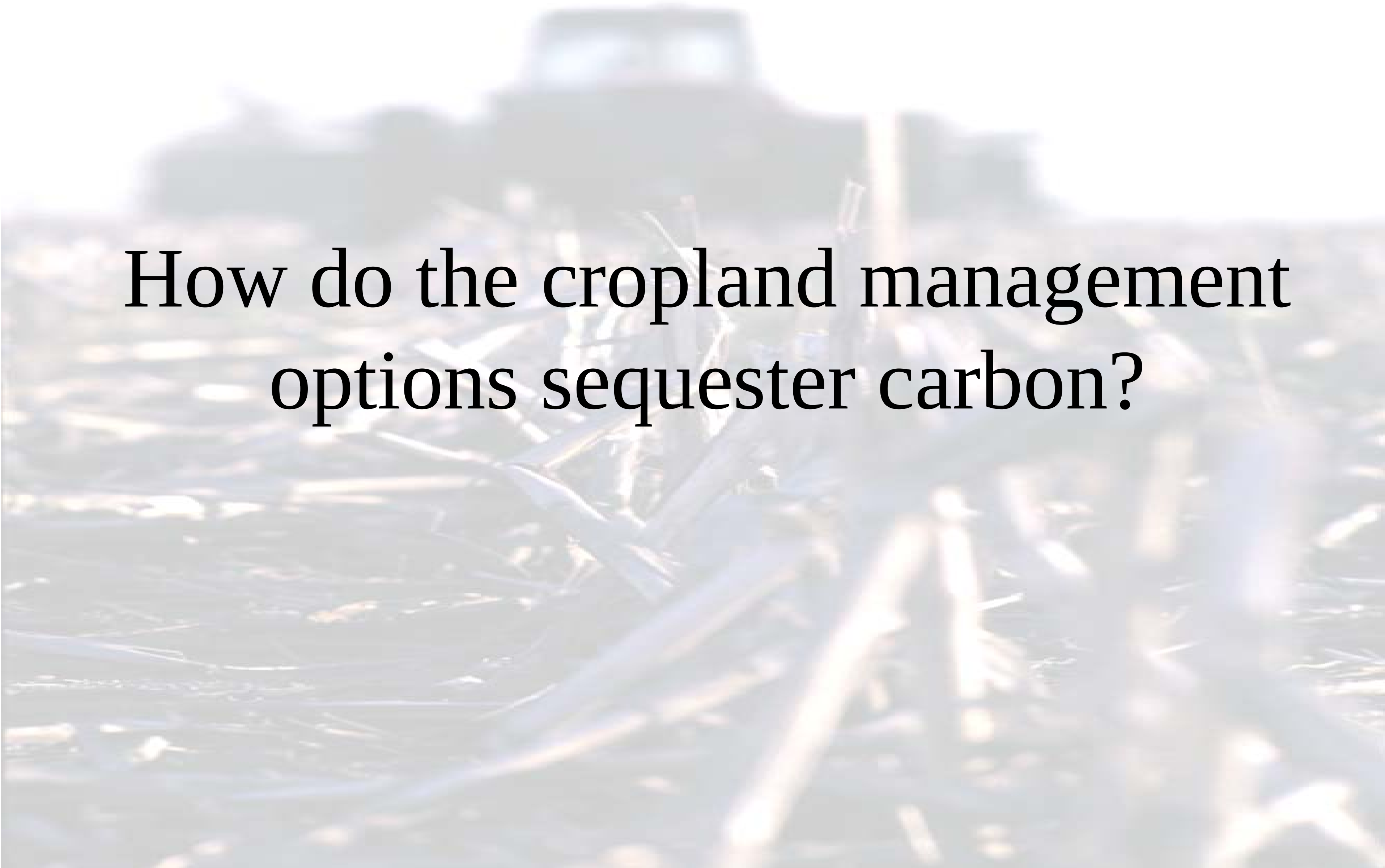
Farmers Weekly (UK)
14 January 2000

Canadian Power Companies pay Iowa farmers US\$5-10 acre^{-1} (= Euro 13-26 ha^{-1}) to convert to no-till.

Why look at soil C sequestration in European croplands ?

European cropland C fluxes

- European croplands (for Europe as far east as the Urals) lose 300 Mt C y^{-1} (Janssens et al., 2003)
- Mean figure for the European Union estimated to be 78 (SD: 37) Mt C y^{-1} (Vleeshouwers & Verhagen, 2002)
- Largest biospheric source of carbon lost to the atmosphere in Europe each year
- Highest uncertainty of all European fluxes
- There is significant potential to decrease the flux of carbon to the atmosphere from cropland, and for cropland management to sequester soil carbon.



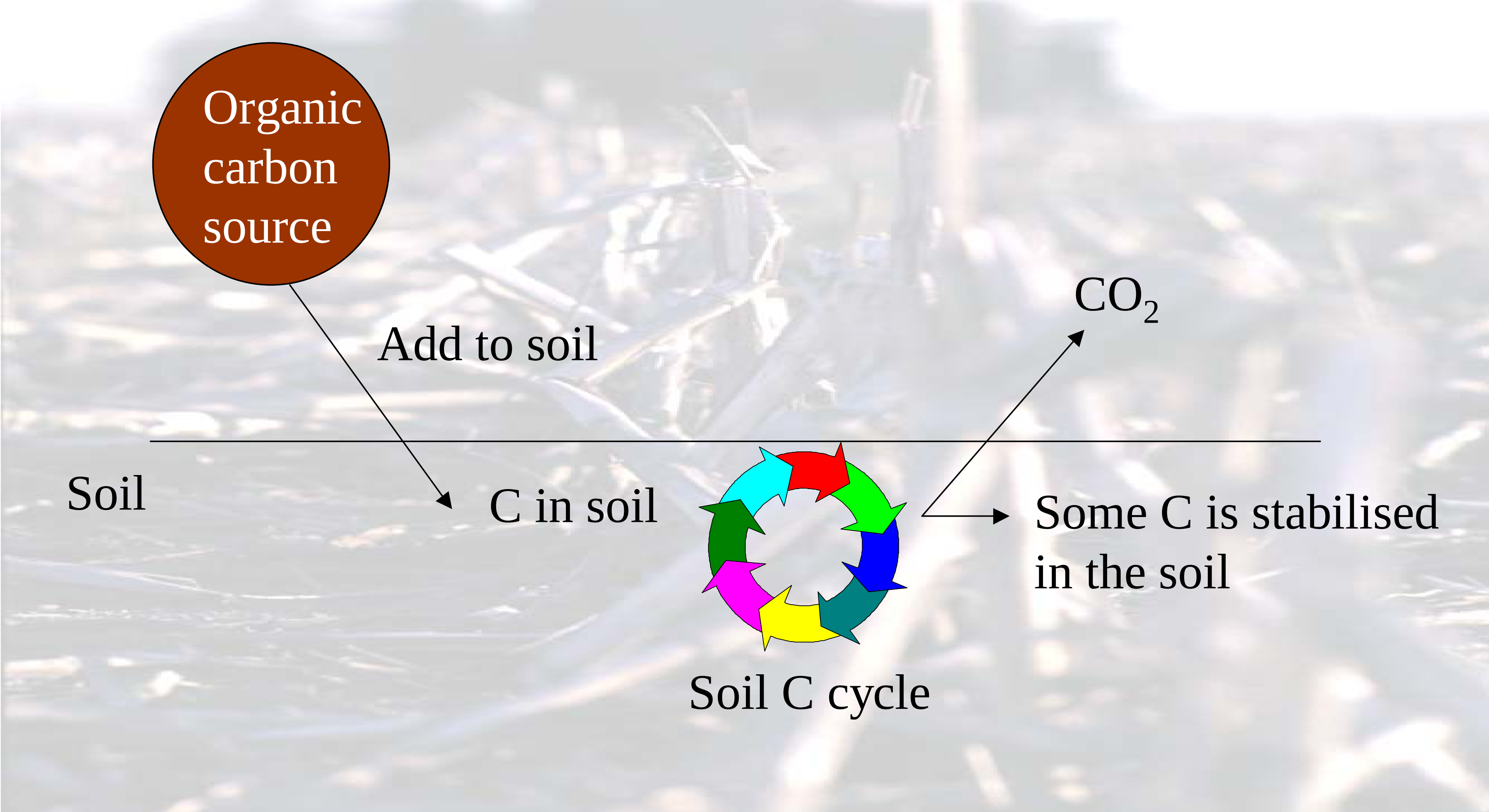
How do the cropland management options sequester carbon?

Options for combating the greenhouse effect on European agricultural land

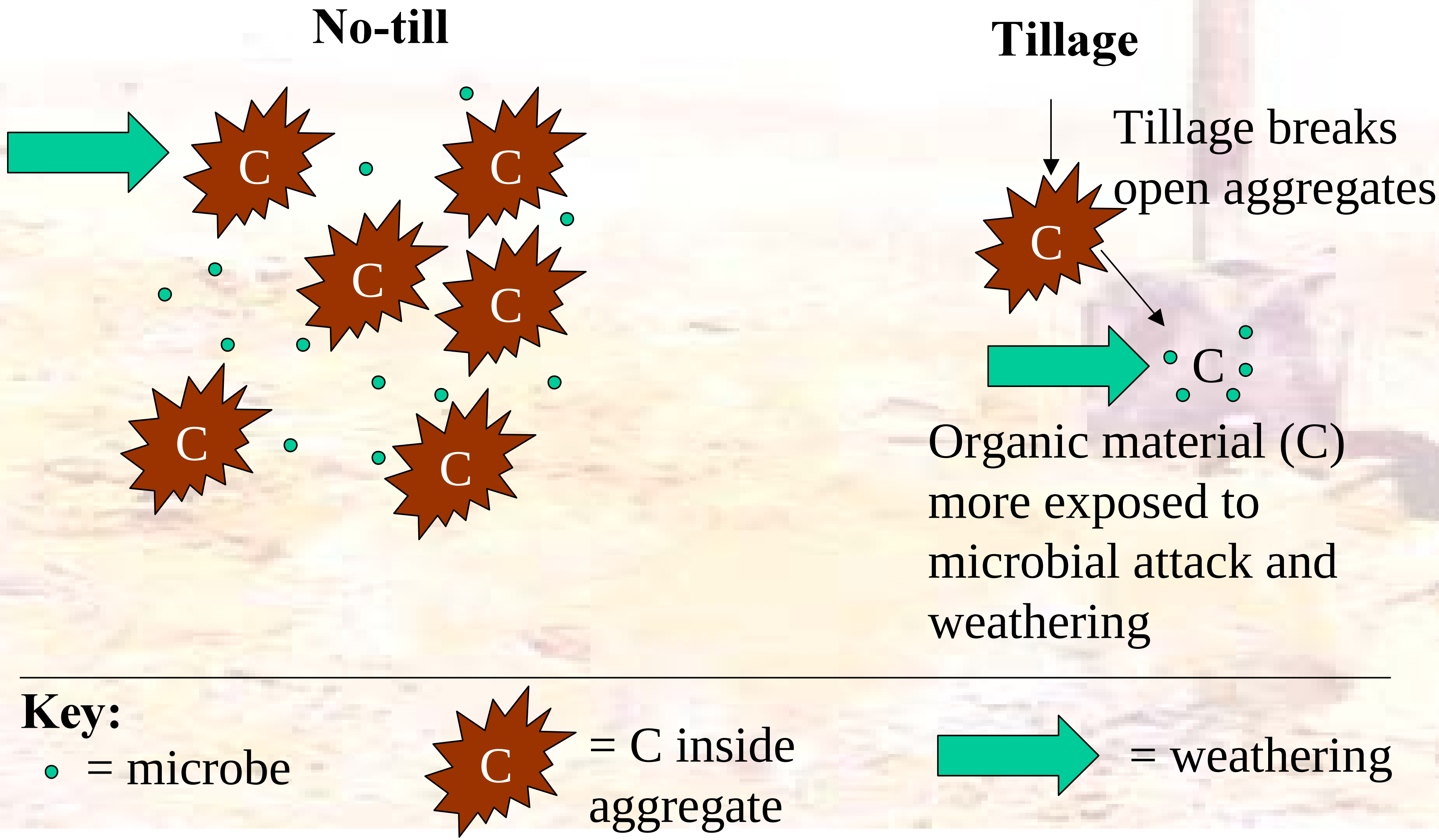
- More efficient use of animal manure
- Application of sewage sludge
- Return surplus cereal straw to the soil
- Convert to no-till agriculture
- Use surplus arable land to de-intensify production (extensification)
- Use surplus arable land to plant woodland
- Use surplus arable land to grow biofuels

Smith *et al*. (2000)

How does it work? - manure, sewage sludge and straw



How does it work? - no-till farming

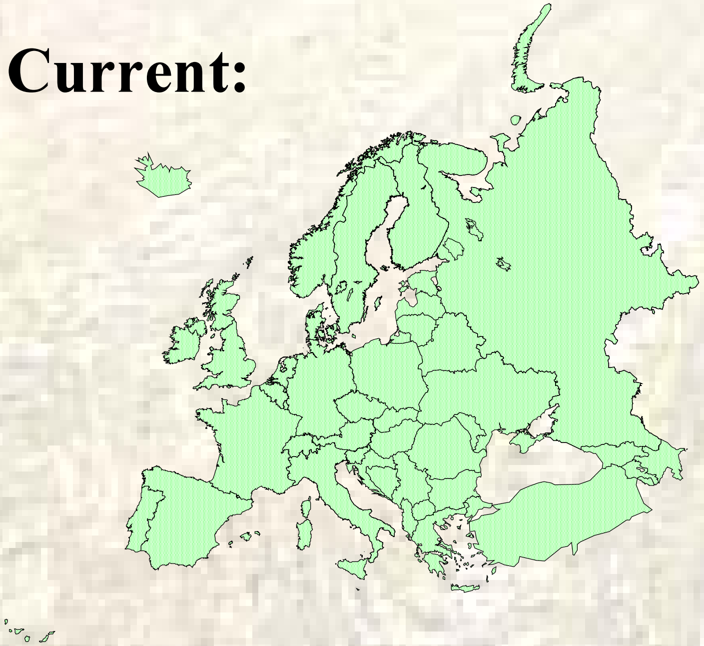


Other impacts of no-till

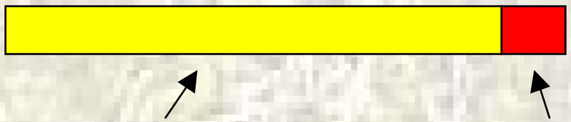
- Slightly increased C cost due to extra herbicide needed for no-till
- Reduced fossil-fuel C costs due to less work with farm machinery
- Overall reduced C costs (in addition to soil C storage; Frye, 1984; Smith *et al.*, 1998)
  - Conventional tillage: 52.8 kg C ha^{-1} y^{-1}
  - No-till: 29 kg C ha^{-1} y^{-1}

How does it work? - agricultural de-intensification

Current:



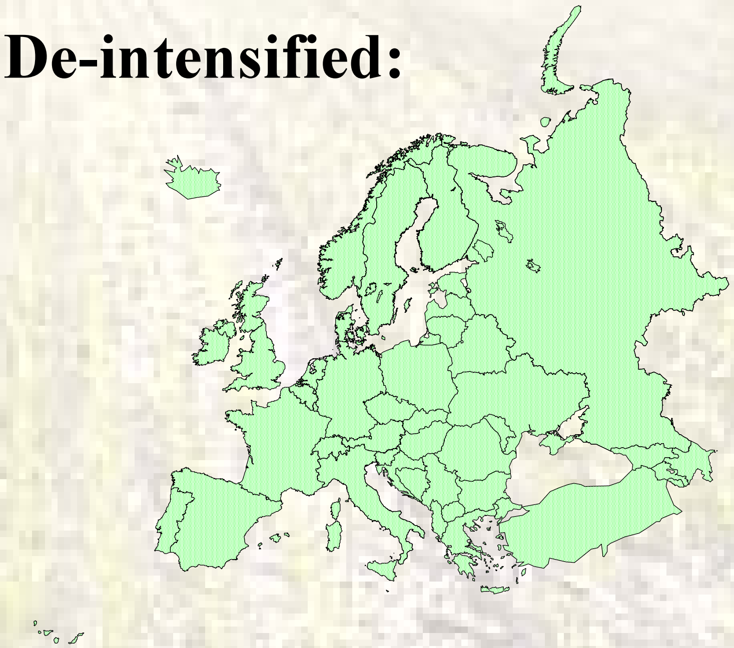
Proportion of land



Intensive agriculture

Surplus arable land

De-intensified:



Proportion of land

Less intensive agriculture:
More grass in rotations

How does it work? - Woodland

Arable crop

Woodland

C inputs to the soil:
small, easily decomposable

C inputs to the soil:
large, more resistant to decomposition

Other impacts of woodland regeneration (ARD)

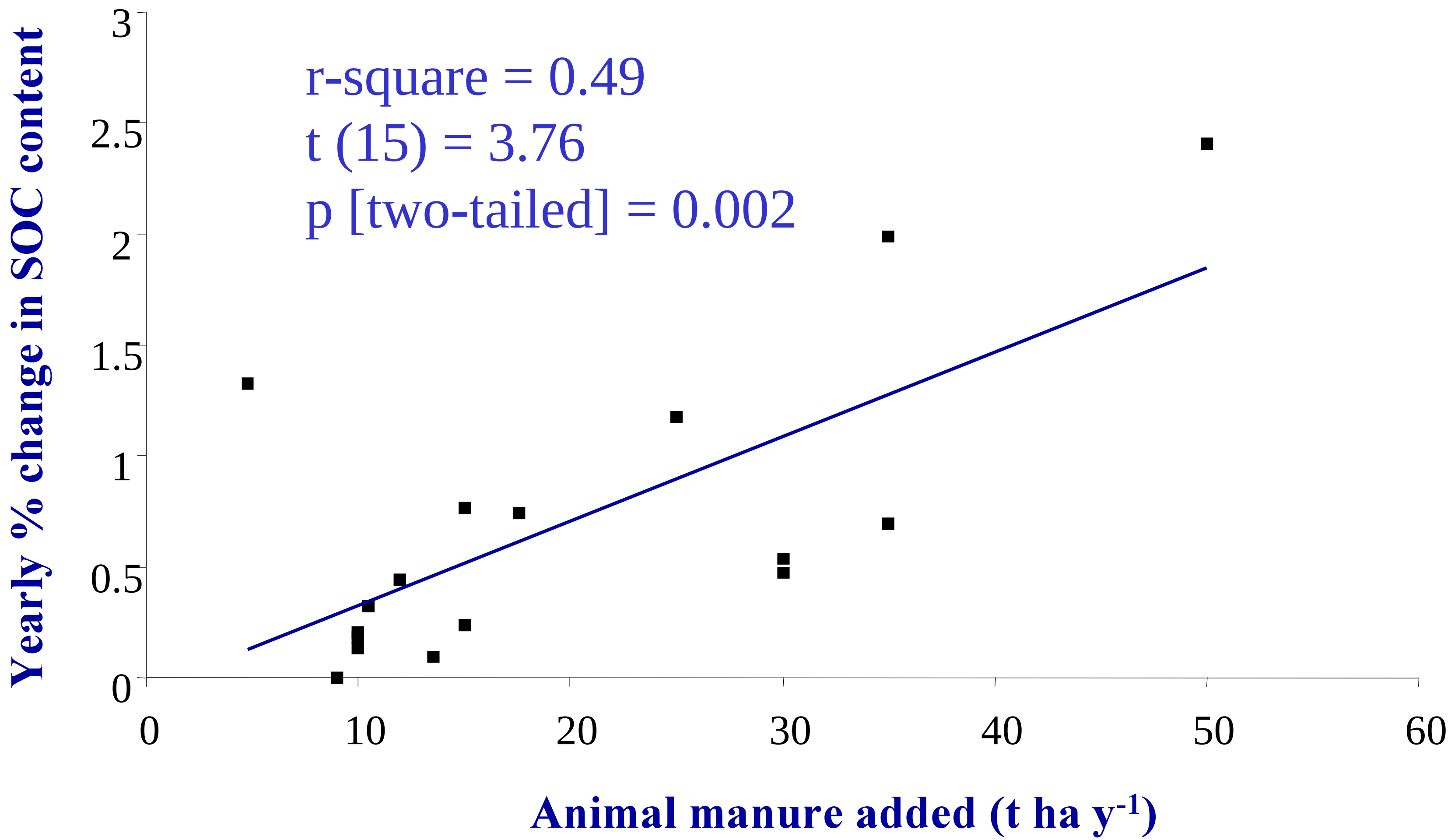
- As well as increased soil C storage, also above-ground C storage in the woody biomass
- C stored in wood each year in growing deciduous trees: 2.8 t C ha^{-1} y^{-1} (Jenkinson, 1971; IPCC, 1996)

Biofuel - How does it work?

- Carbon stored in the soil PLUS fossil-fuel substitution:
- Carbon is fixed in the plant from CO_2 by photosynthesis
- The plant is harvested and burned, releasing the CO_2 back into the atmosphere
- For every unit of energy produced from biofuels, that is one unit of energy that is produced without releasing fossil fuel C to the atmosphere

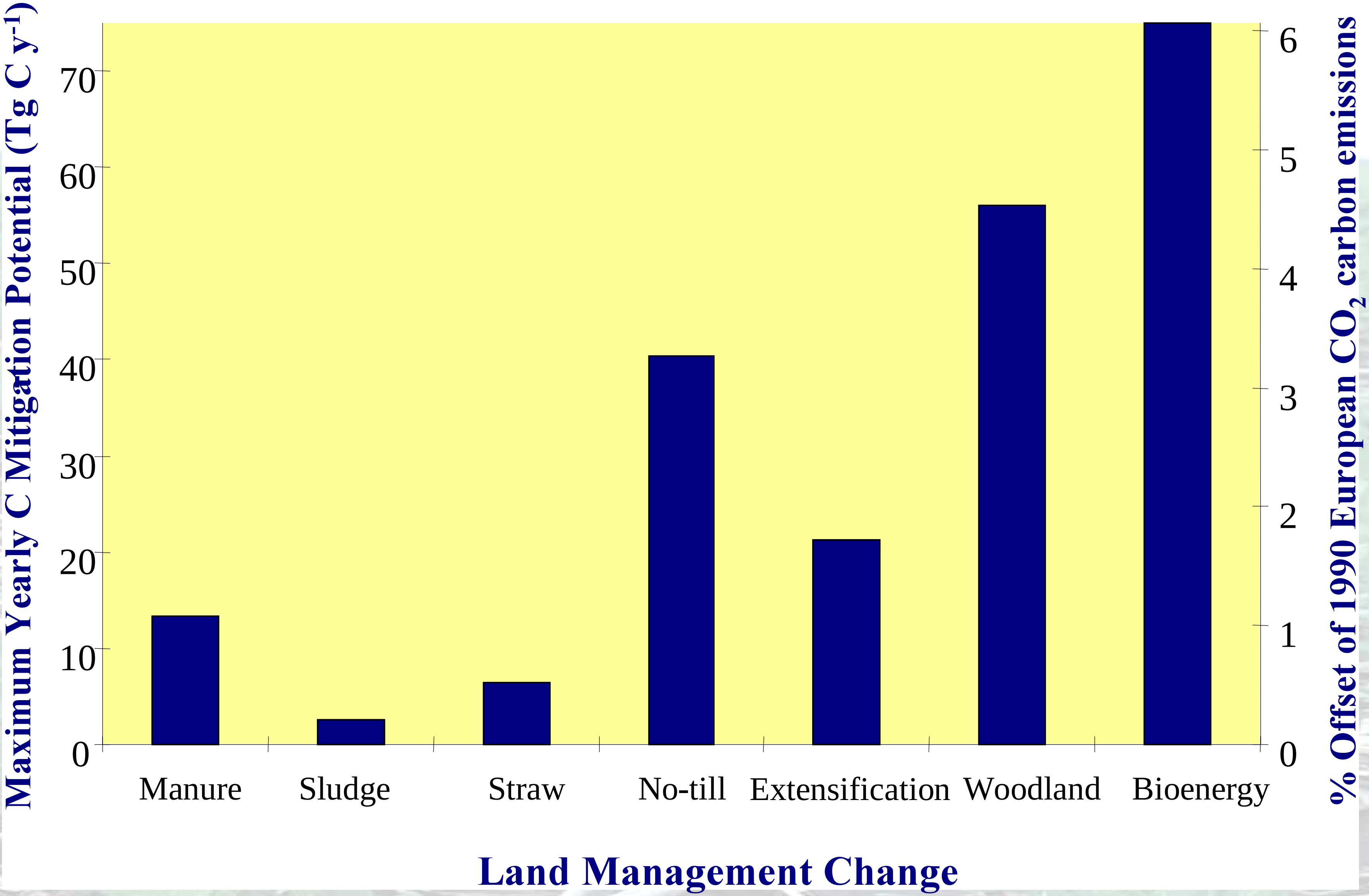
Estimates of the C mitigation potential of European croplands

SOC changes with animal manure



Smith *et al.*, 1997

Carbon mitigation potential / CO_2-C offsets



Smith *et al.*, 2000 *GCB*

Combined options

Policy decision 1:
Surplus crop land

- Extensification
- Woodland regeneration
- Bioenergy crops

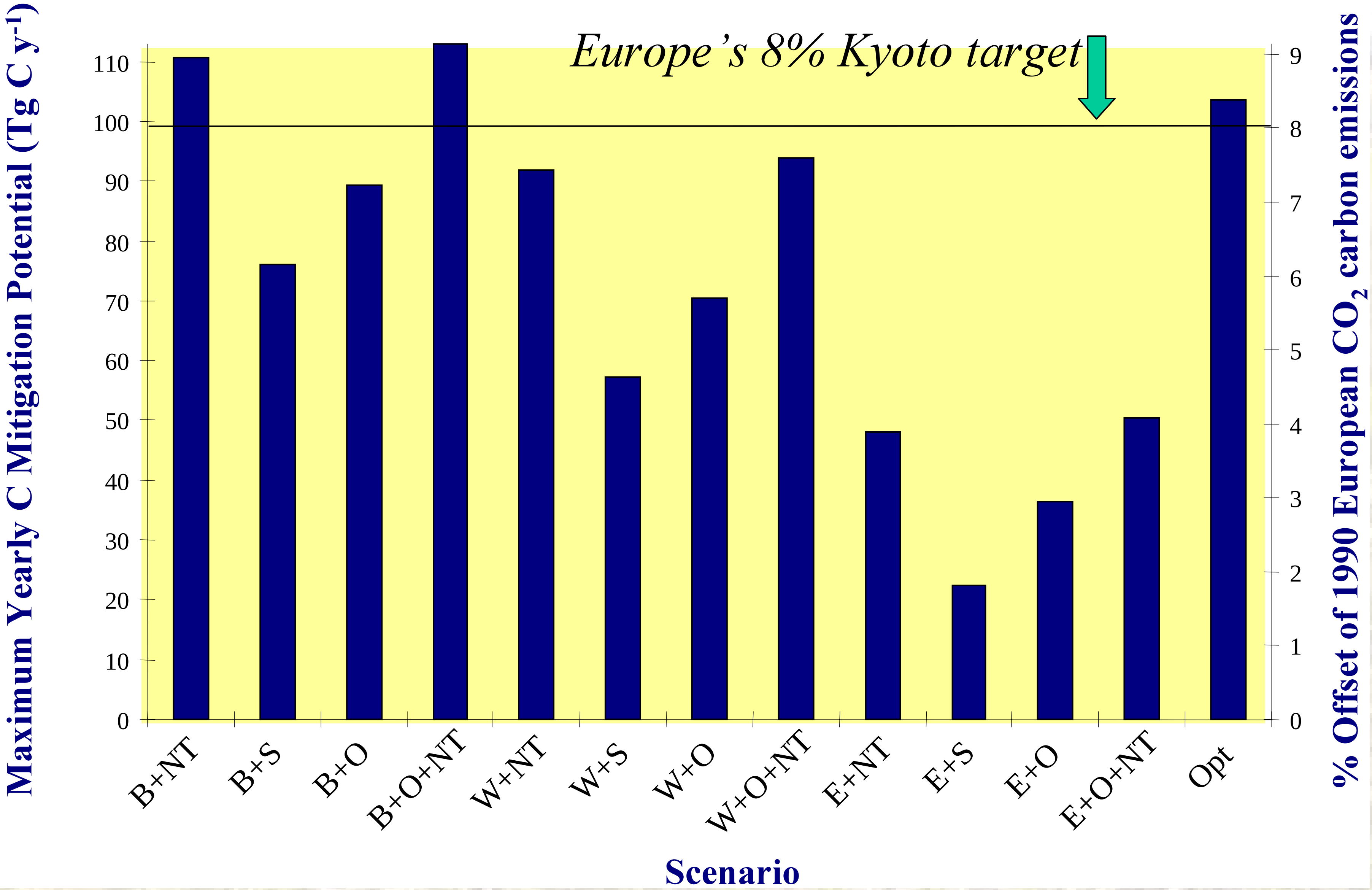
Combined with..

Policy decision 2:
Remainder of crop land

- No-till farming
- Straw incorporation
- Organic amendments (low)
- Organic amendments (high) plus no-till

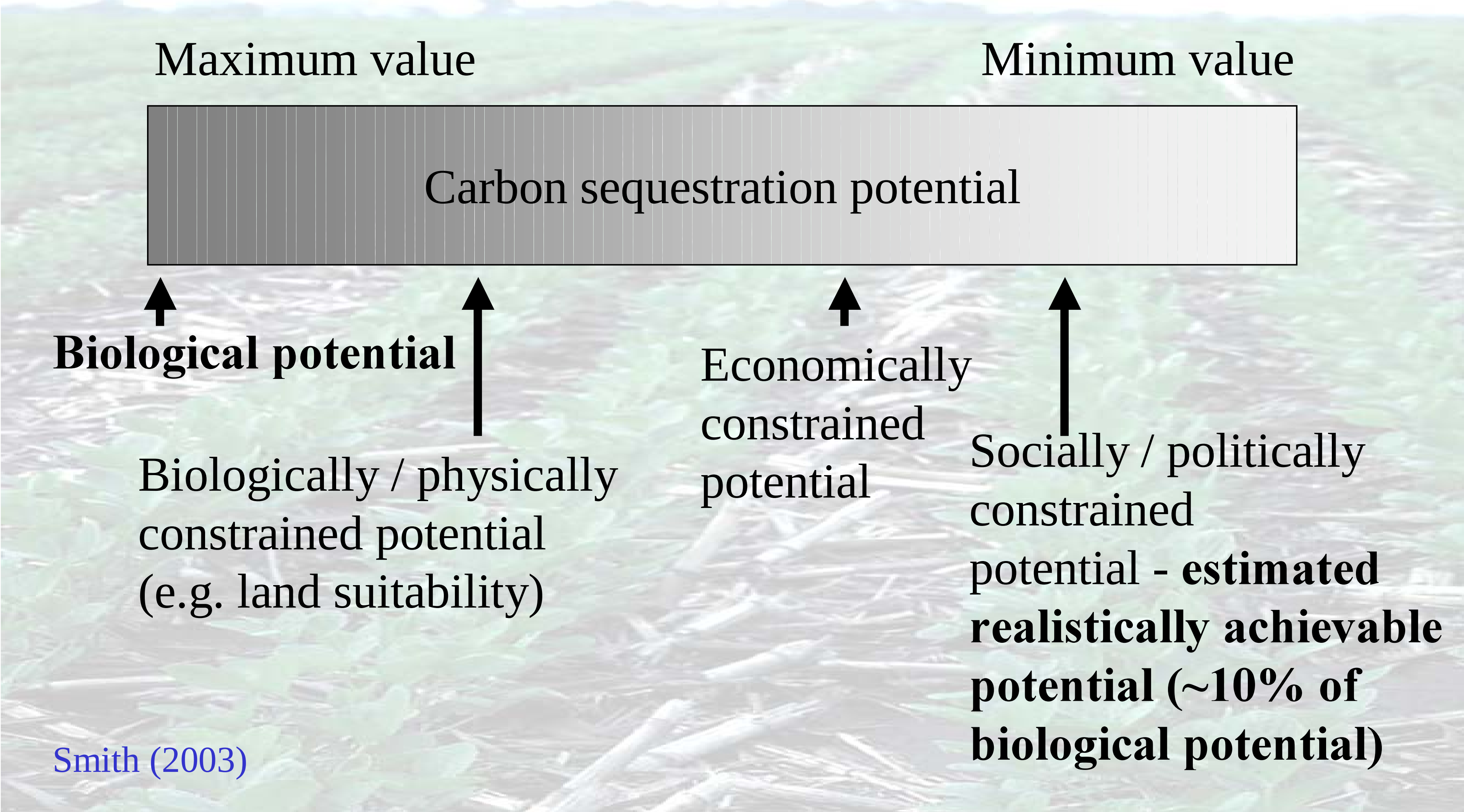
Smith *et al.*, 2000 *GCB*

Combined land-management options



Smith *et al.*, 2000 *GCB*

What is meant by C sequestration potential ?



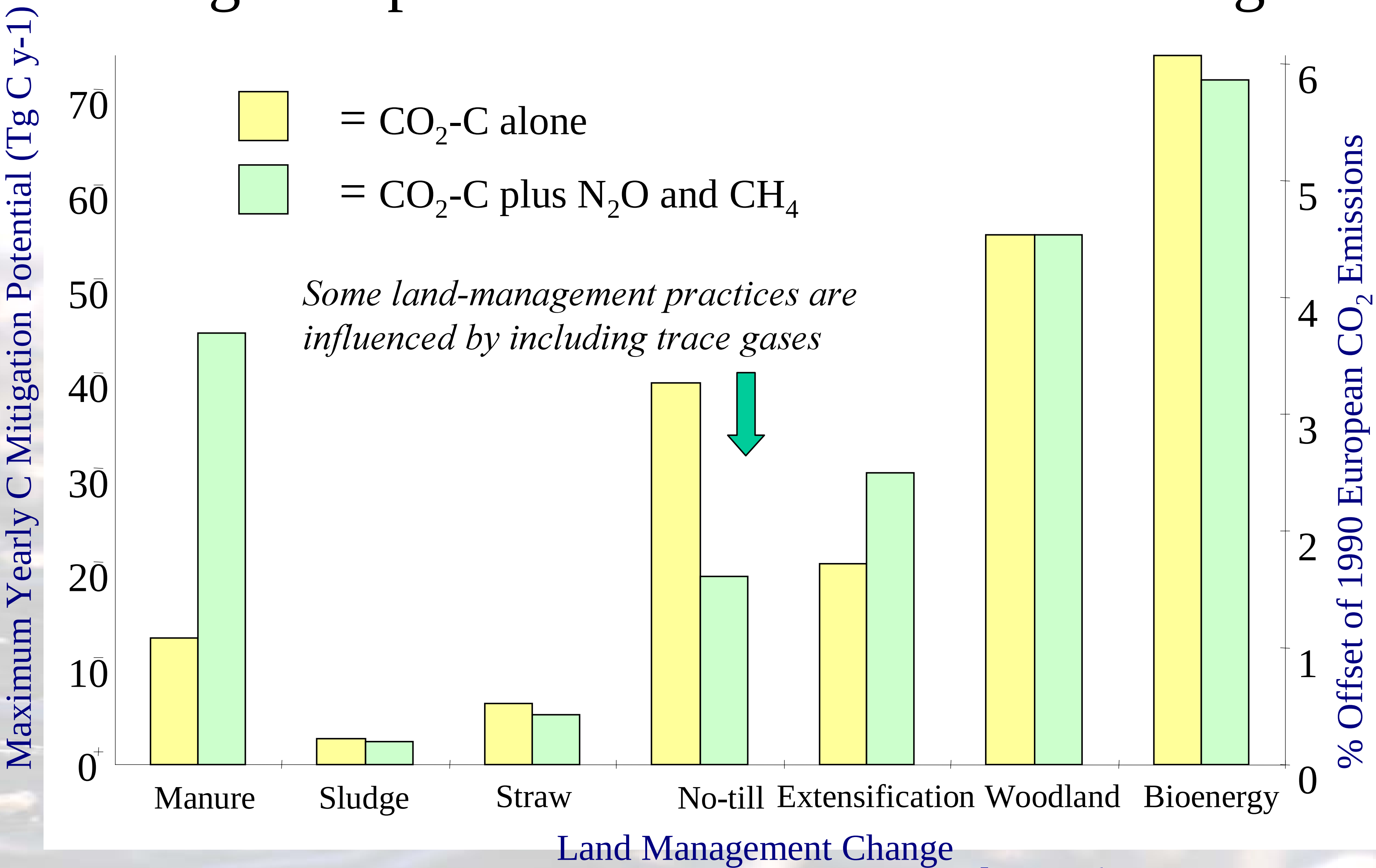
A further word of caution...

Global warming potential

Gas/ Time span	20 years	100 years	500 years
Carbon dioxide	1	1	1
Methane	56	21	6.5
Nitrous Oxide	280	310	170

IPCC, 2001

C mitigation potential with and without trace gases



Smith *et al.*, 2001 *NCAE*

Global significance of the European cropland C sequestration potential

European croplands in the context of global soil C sequestration

- Potential in European croplands over 50 years ~ 0.4 Pg (Smith et al., 2000 – more if grasslands & wetlands included; Freibauer et al., 2003)
- Total global potential over 50 years ~ 45 Pg
- Historical global C losses from soils - 40-90 Pg (Lal, 1999; Schimel, 1995; Houghton, 1999)
- Globally - the biological potential exists to reverse most of historical C losses from soils over the next 50 years

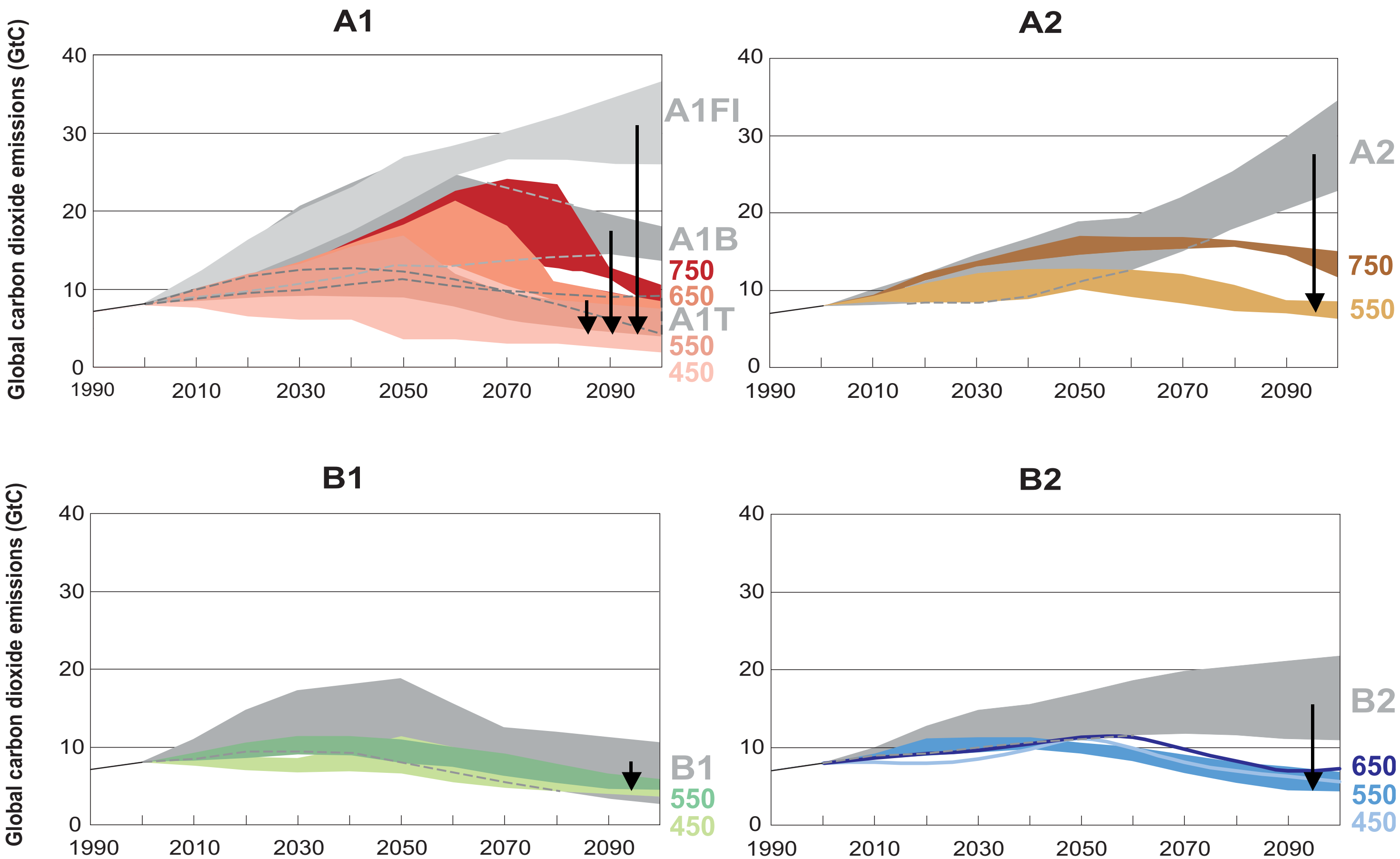
Impact on atmospheric CO_2

- Atmospheric C increasing at a rate of 3.2 ± 0.1 Pg C y^{-1} (Schimel et al., 2001; IPCC, 2001)
- Global soil C sequestration potential = 0.9 ± 0.3 Pg C y^{-1} (Lal, 2003)
- Duration of sequestration potential limited – how important will sequestration be in the long term, by 2100?

Carbon sequestration in the long term – the energy gap

- In the future population will grow, the population will become wealthier and per-capita energy demand will increase (all SRES scenarios – IPCC, 2000)
- The extent to which these changes will occur differs between SRES scenarios
- For any given atmospheric CO_2 stabilization target (e.g. 450, 550, 750 ppm), the necessary emission trajectories can be calculated
- The difference between the necessary emission trajectory for stabilisation and the emissions associated with the estimated global energy demand is the emission / energy gap.

The energy / emission gap under different SRES scenarios



IPCC TAR WGIII (2001)

- Current yearly atmospheric C increase = 3.2 ± 0.1 Pg C y^{-1}
- Emission gaps here of up to 25 Pg C y^{-1} by 2100
- Maximum yearly global C sequestration potential = 0.9 ± 0.3 Pg C y^{-1}

Soil C sequestration in the future

- Soil carbon sequestration will play only a minor role in controlling carbon emissions by 2100
- Non carbon-emitting energy technologies will be needed to meet increased energy demand by 2100
- Drastic reductions in C emissions are required during the next 20-30 years if atmospheric CO_2 levels are to be stabilised at 450-650 ppm (IPCC, SRES, 2000).
- During that critical period, soil C sequestration could help to reduce emissions as new energy technologies are developed.

Summary of this part (Smith, 2003)

- Cropland offers a significant opportunity for GHG mitigation (mainly through soil C sequestration) to help meet short-term GHG mitigation targets
- Carbon storage is temporary, and sequestration options will continue to be effective for a limited period only (20-50 years)
- European croplands will play only a small role globally, but could play a large role regionally (i.e. in Europe)
- Globally, C sequestration should play an important role over the next 20-30 years, a critical period
- In the long-term, non-C emitting energy sources are the only solution for stabilising the atmospheric CO_2 concentration

Agro-ecosystem vulnerability

Ecosystem services in Agro-ecosystems

- Agricultural production
  - Changing crop yields due to climate change, N deposition, timeliness of operations ✓ (ACCELERATES)
  - Changing profitability due to socio-economic and policy change (CAP reform) ✓(ACCELERATES)
  - Changing risk (greater yield variability arising form future climatic variability) ✓ (ACCELERATES)
  - Water availability (competing use for irrigation) ATEAM water group
- Environmental quality
  - Air (trace gas emissions) ✓✓
  - Soils (carbon storage, erosion, salinisation) ✓✓
  - Water (nitrate pollution, pesticides) ✓✓
  - Biological resources (the distribution and diversity of natural species) within agricultural landscapes) ✓
  - Landscape / leisure / amenity value Land-use issue – dealt with there

ATEAM - What we will deliver

- Soil carbon, soil organic matter, soil organic nitrogen reserves (fertility), soil water – for 1990 baseline and changes under all SRES, 1990-2100 – deliver November 2003
- N_2O fluxes (via denitrification) and nitrate fluxes (as above – deliver April 2004)
- Biofuel suitability maps under all scenarios – September 2003
- Convert all to SPpot for 1990 and onwards
- Agricultural productivity etc. - ACCELERATES