

AVEC Summer School

**"Integrated Assessment of Vulnerable Ecosystems under
Global Change"**

**Agricultural systems
and their vulnerability
to climate change**

Marco Bindi

DISAT-University of Florence, Italy

Peyresq / France

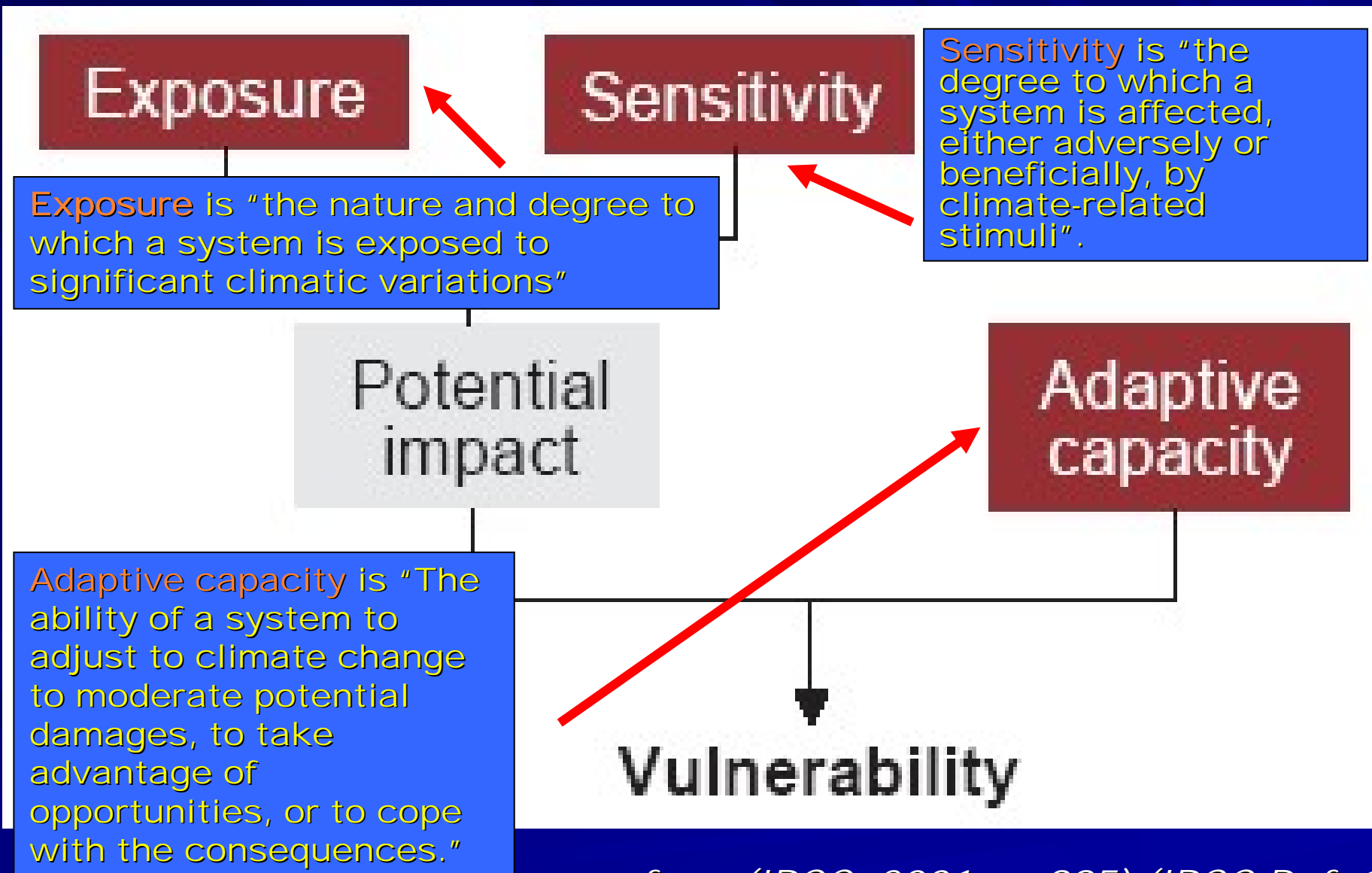
Sunday 18 September – Saturday 1 October 2004

DEFINITION of VULNERABILITY (in Climate Change studies)

- "*Vulnerability* is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes"
- "*Vulnerability* is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity"

from (IPCC, 2001, p. 995) (IPCC Def. 1)

FACTORS of VULNERABILITY



from (IPCC, 2001, p. 995) (IPCC Def. 1)

MAJOR QUESTIONS TO ANSWER

(to define **vulnerability** of agricultural systems to climate change)

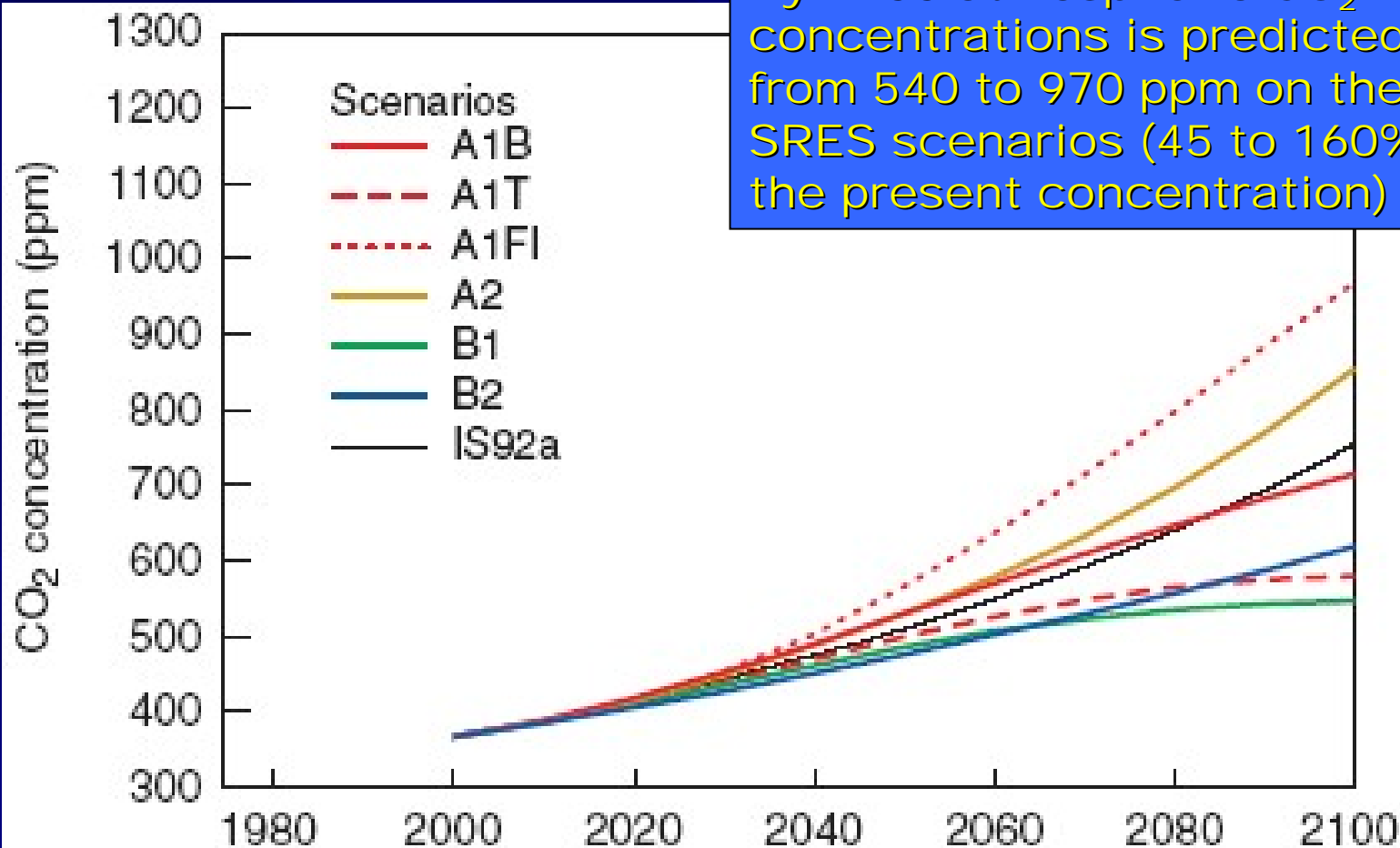
- How is climate changing ? (**Exposure**)
- What is the sensitivity of agricultural systems to climate change ? (**Sensitivity**)
- How will climate change affect agricultural systems ? (**Potential Impact**)
- How can agricultural systems adapt to a changing climate ? (**Adaptive capacity**)

Main climate change elements affecting agricultural systems

- *Atmospheric CO₂ concentration* (plant gas exchanges)
- *Air temperature* (duration of the growing period, leaf area expansion, respiration, etc.)
- *Precipitation* (water availability, photosynthetic efficiency, etc.)
- *Extreme weather events* (e.g. drought, heat stresses, hails, storms, etc.)

Future trends in Greenhouse Gases

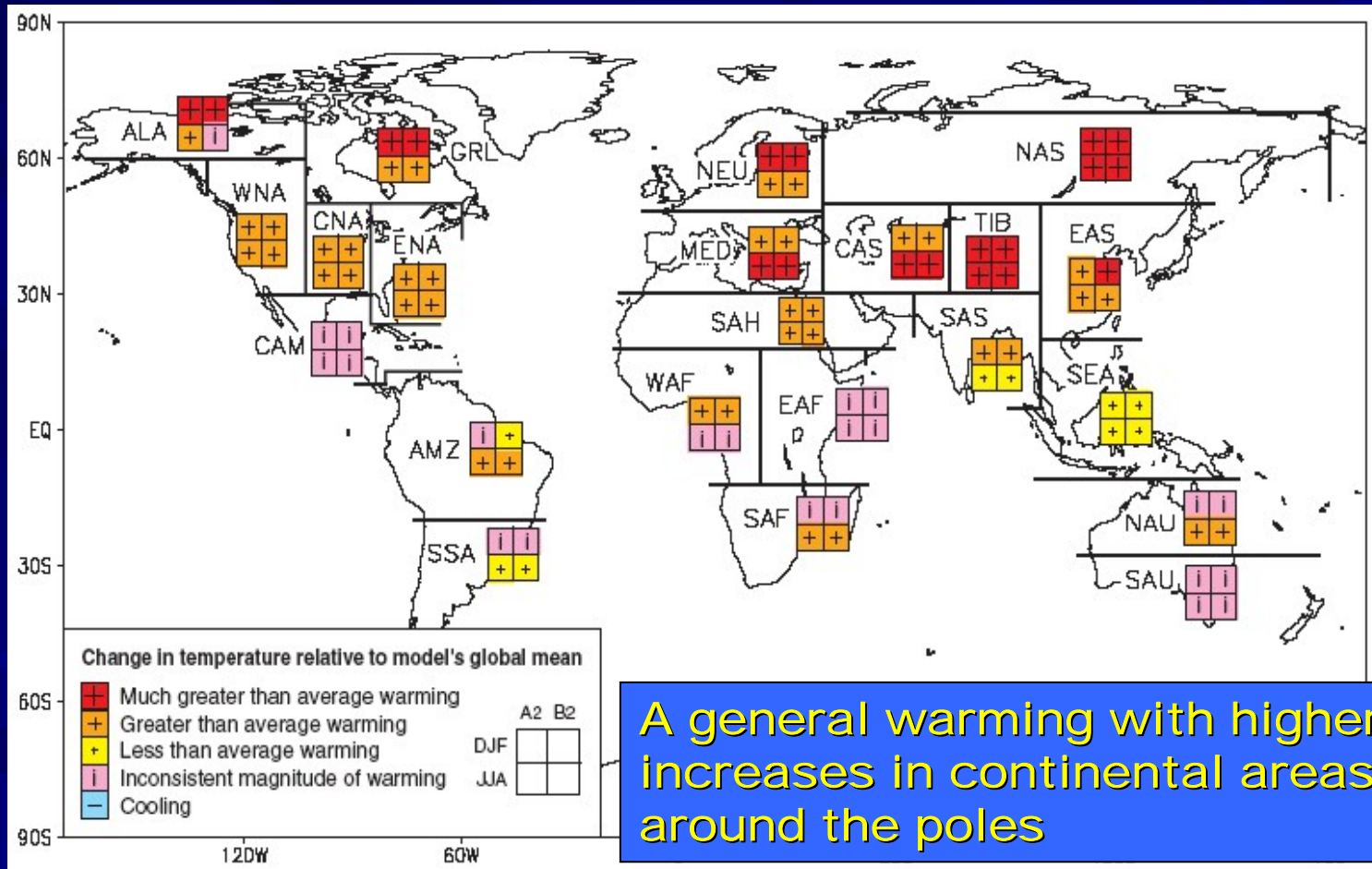
■ Projections of Future CO₂ concentration



By 2100 atmospheric CO₂ concentrations is predicted to range from 540 to 970 ppm on the basis of SRES scenarios (45 to 160% above the present concentration)

GCMs future climate scenarios

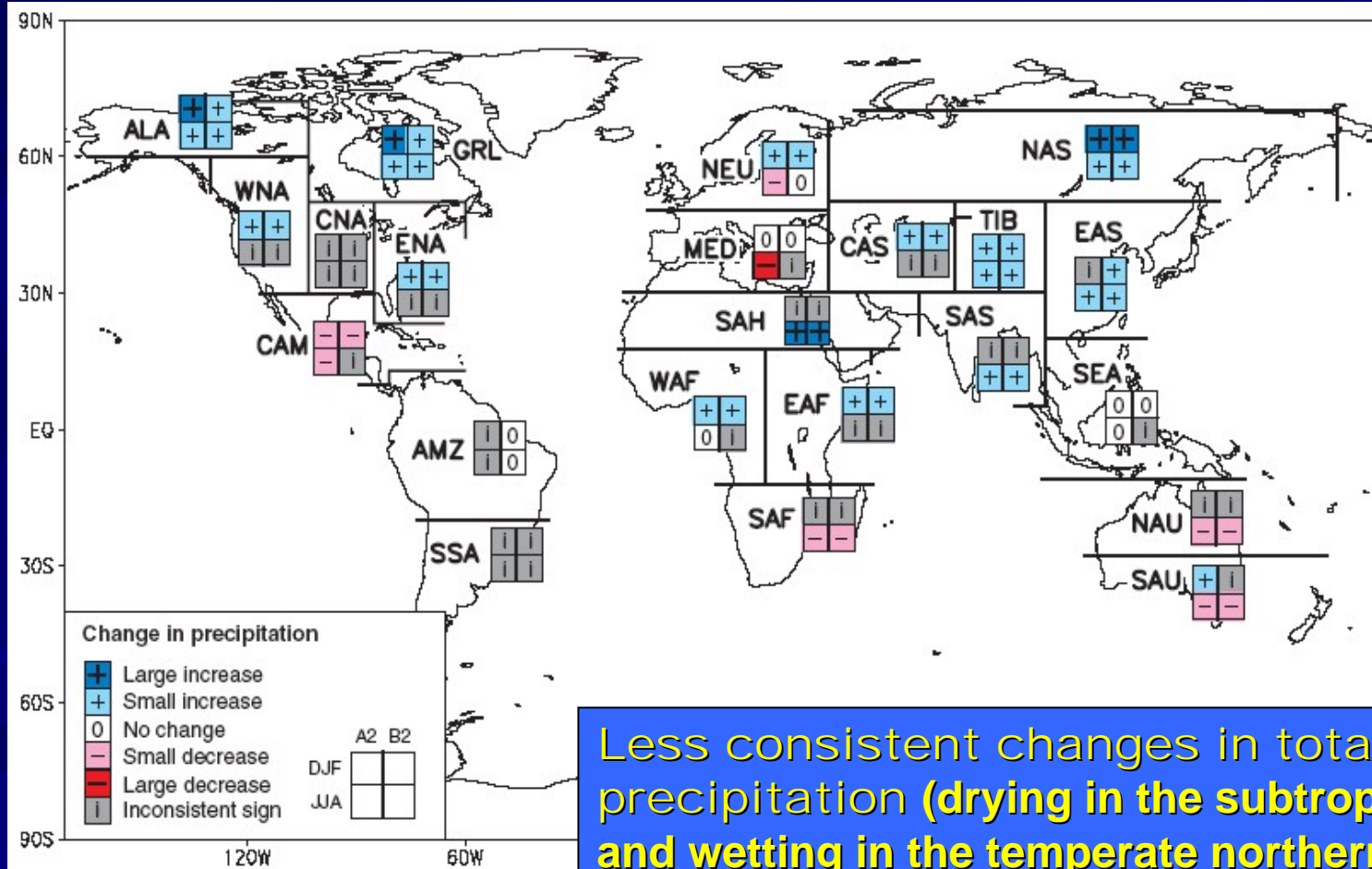
Mean changes in Temperature



A general warming with higher increases in continental areas and around the poles

GCMs future climate scenarios

Mean changes in Precipitation



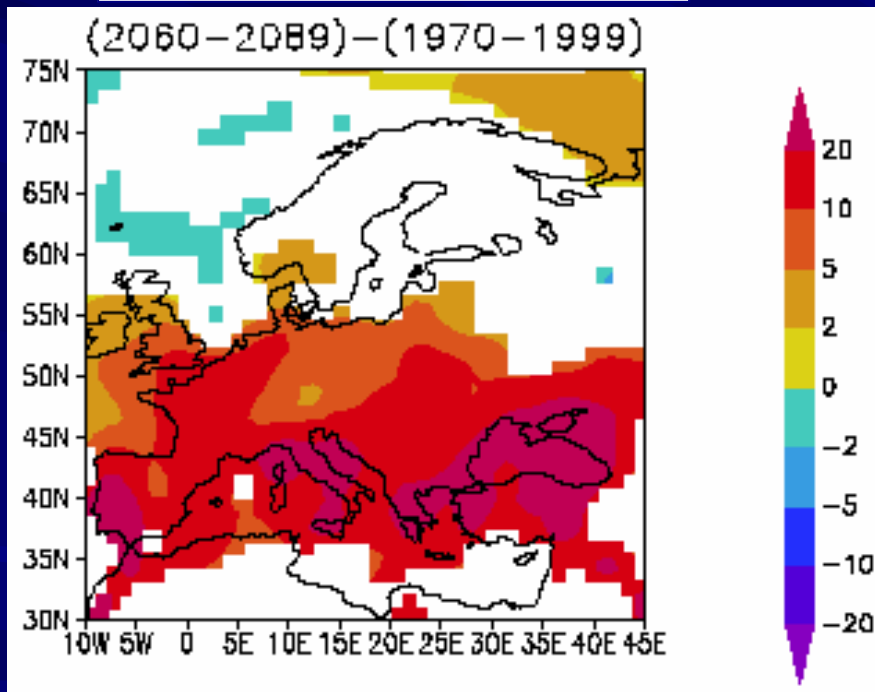
from May and Vos, 2001

Less consistent changes in total precipitation (drying in the subtrop. belts and wetting in the temperate northern hemisphere)

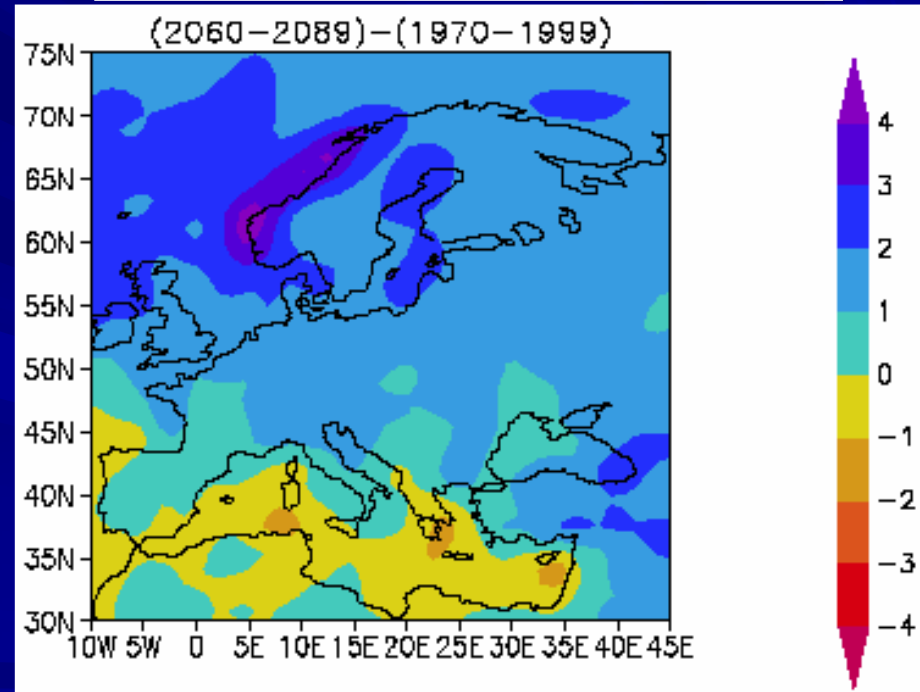
GCMs future climate scenarios

- Changes in the frequency of climatic extremes

Dry spell length [d]



Rainfall intensity [mm/d]



An evident increase in climatic extremes
(dry spell length and rainfall intensity)

from May and Vos, 2001

How is climate changing ? (Exposure)

Answer

Agricultural systems are highly exposed through:

Increases in atmospheric CO₂ concentration

Changes in mean climate (temperature, precipitation)

Increases in climate extreme events

What is the sensitivity of agricultural systems to climate change? (Sensitivity)

Components of the agricultural system



What is the sensitivity of agricultural systems to climate change ? (Sensitivity)

Components of the agricultural system

Crops

- *Crop phenology (i.e. length of growth season) (temperature)*
- *Gas and water exchange fluxes (i.e. photosynthesis, transpiration, etc.) (CO_2 , temperature, precipitation)*
- *Crop yield (CO_2 , temperature, precipitation)*
- *Yield quality (CO_2)*

Livestock

- *Animal growth and reproduction (temperature)*
- *Animal health (temperature, air humidity)*
- *Forage quality (i.e. nutrient content C/N) (CO_2)*

What is the sensitivity of agricultural systems to climate change ? (Sensitivity)

Components of the agricultural system

Pests and Diseases

- *Proliferation of insect and pests (longer growing seasons, higher possibility to survive during winter time) (temperature, air humidity)*
- *Consumption rate of insect herbivores (quality of the biomass of host crop, e.g. leaf N%) (CO₂)*
- *Spread of both wind-borne pests and bacteria and fungi (wind)*

Weeds

- *Alteration of the weed-crop competitive interactions (C3 and C4 species) (CO₂)*
- *Effectiveness of herbicides (temperature)*

What is the sensitivity of agricultural systems to climate change ? (Sensitivity)

Components of the agricultural system

Available water

- *Soil water content (precip. and temperature)*
- *Level of water tables (precip. and temperature)*
- *Risk of water salinisation (sea level)*

Soil fertility and erosion

- *Decomposition of soil organic matter (precip. and temperature)*
- *Cycling of the main nutrient elements in the soil-plant-atmosphere system (i.e. enhancement of CO₂ and N₂O greenhouse gas emissions) (temperature)*
- *Plant nitrogen fixation (temperature)*
- *Wind erosion (wind, precip.)*
- *Water erosion (i.e. run-off) (precip.)*

What is the sensitivity of agricultural systems to climate change ? (Sensitivity)

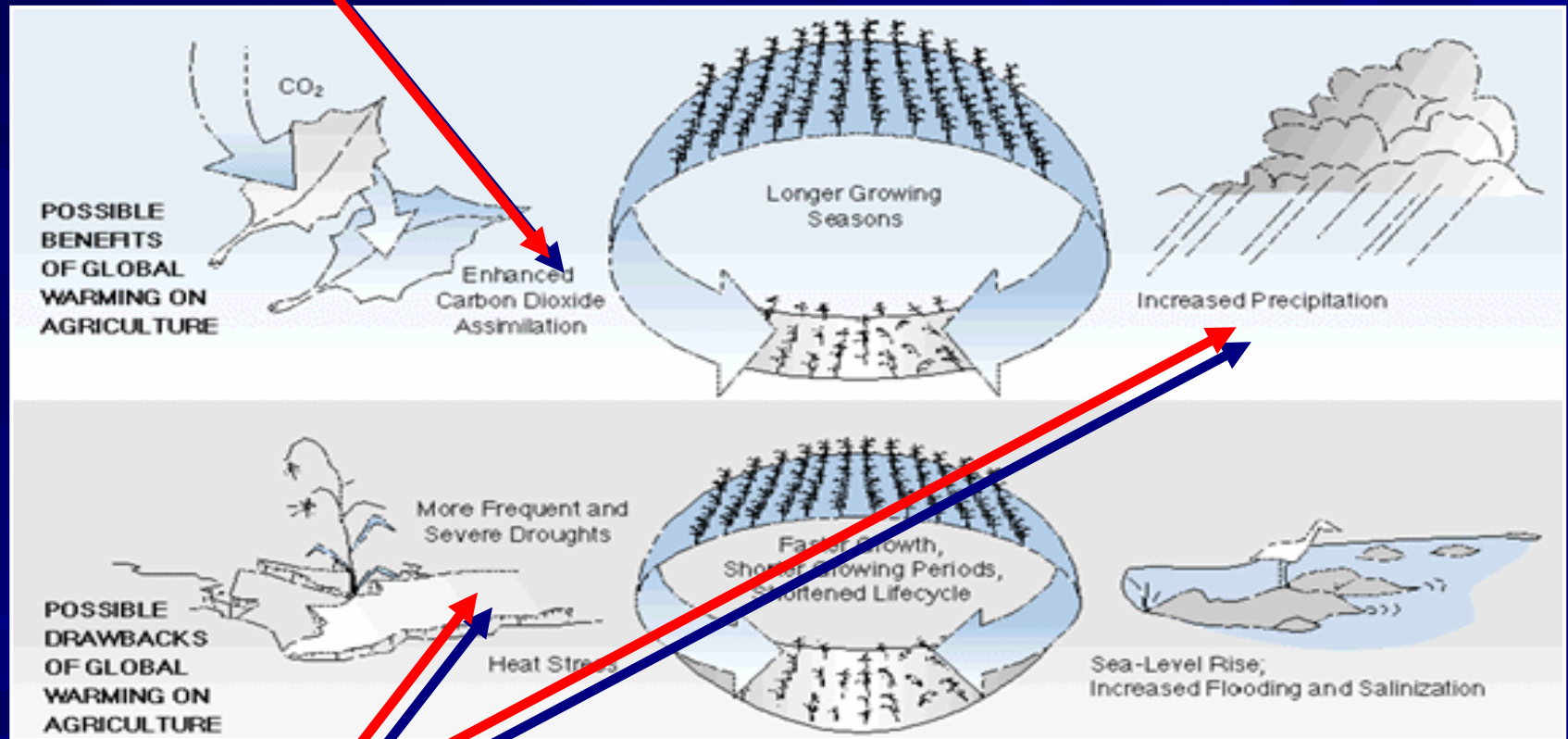
Answer

The sensitivity of agricultural systems to climate change is very high because all the components of the systems are strongly affected

What is the impact of climate change on agricultural systems?
(Potential Impact)

Approach in climate change impact studies

Direct Impact: Stimulating crop photosynthesis and water use



Indirect Impact: Affecting the length of the growth season, the plant water availability, etc.

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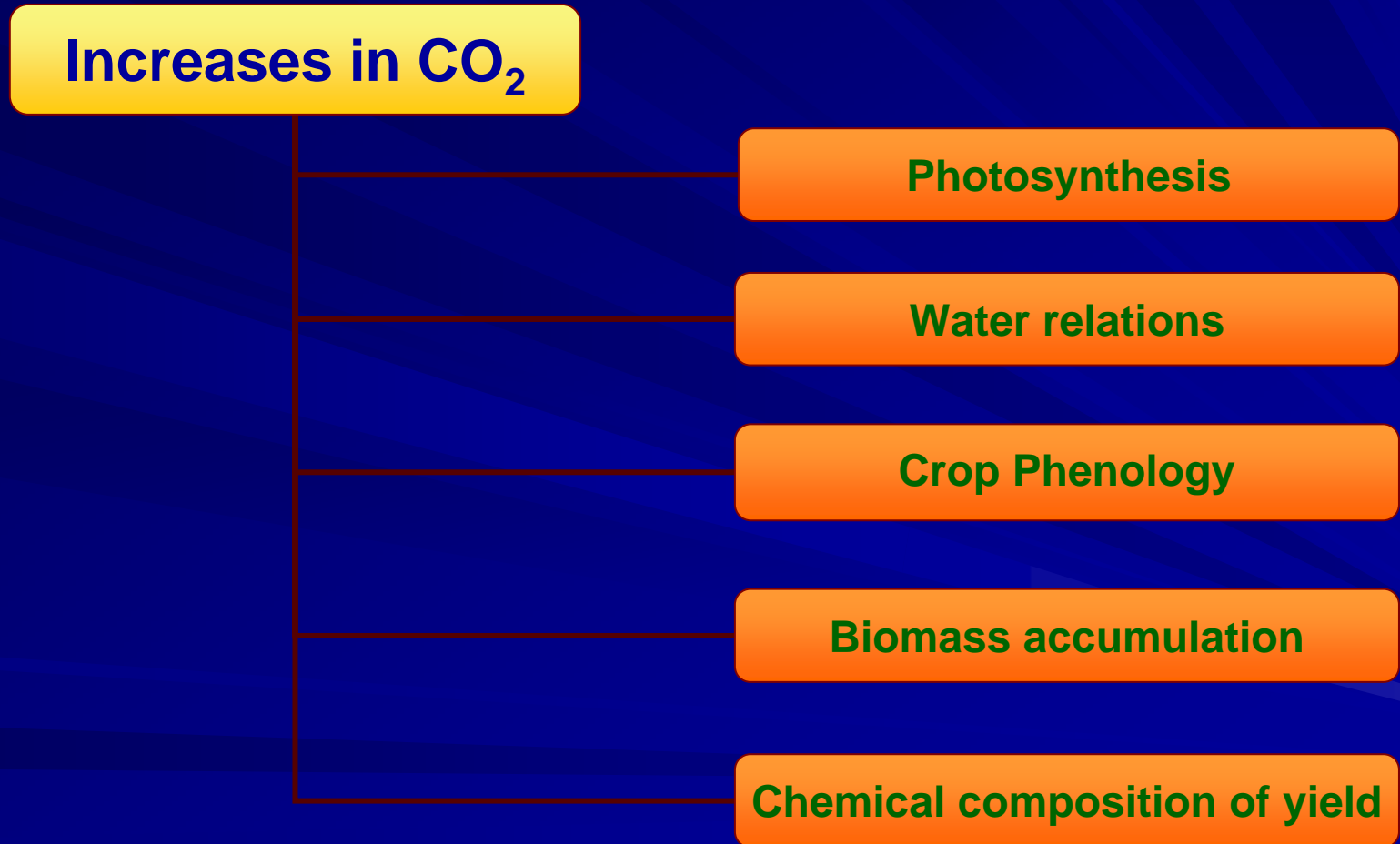
What is the impact of climate change on agricultural systems ? (Potential Impact)

Tools and Objectives in climate change impact studies

Impact	Direct	Indirect	Direct + Indirect
Tools →	CO ₂ experiments (laboratory, greenhouse, OTC, FACE)	- Bio-climatic index - GCMs	- Crop Simulation models - GCMs - CO ₂ experiments
Objectives →	Physiological responses of crops	Shifting of the suitable areas for crop growth	Crop development, yield and production

What is the impact of climate change on agricultural systems ? (Potential Impact)

Direct Impact

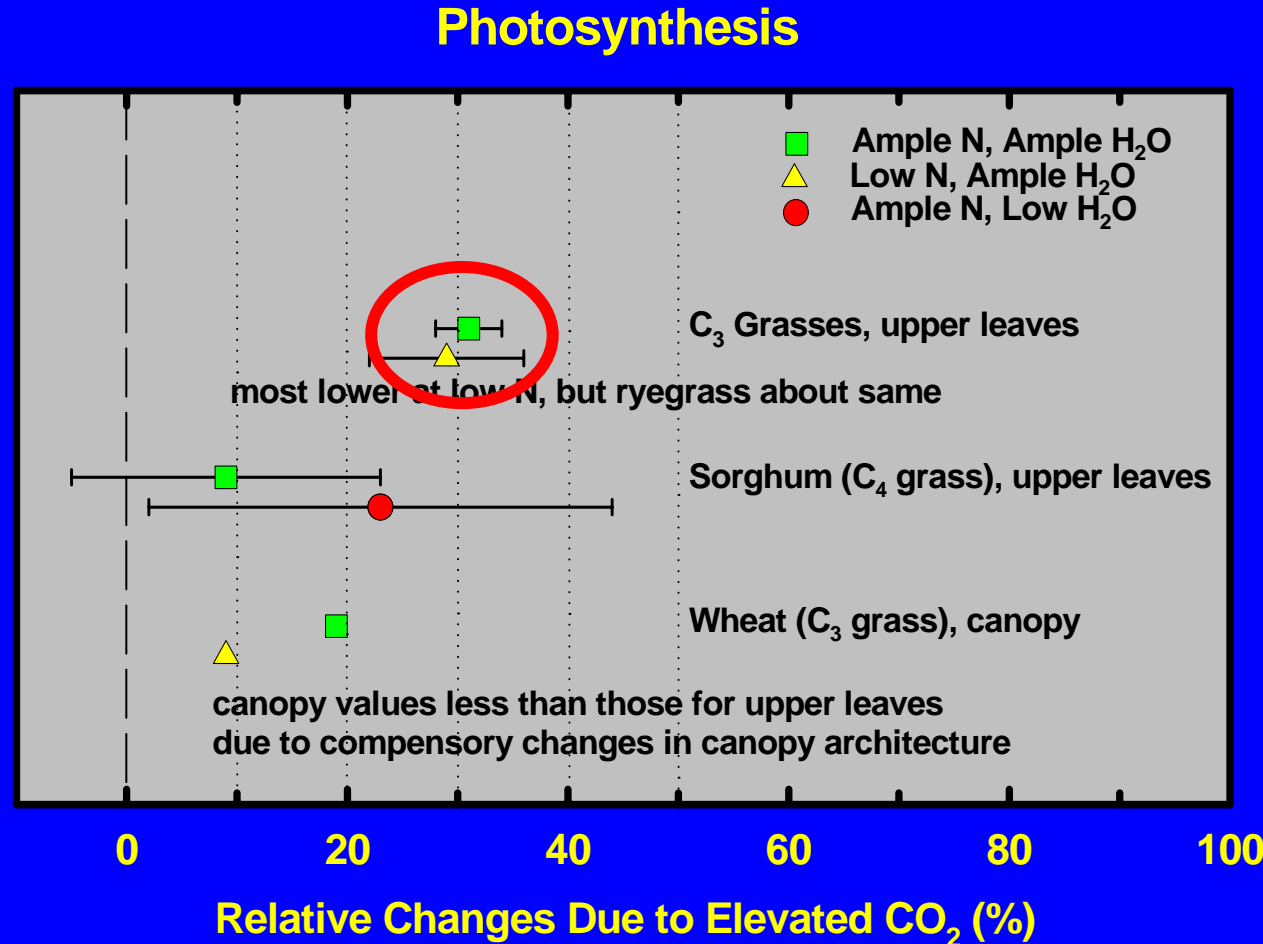


What is the impact of climate change on agricultural systems ? (Potential Impact)

Photosynthesis

Photosynthesis

- General Increase, with larger responses for C₃ species (+31%)

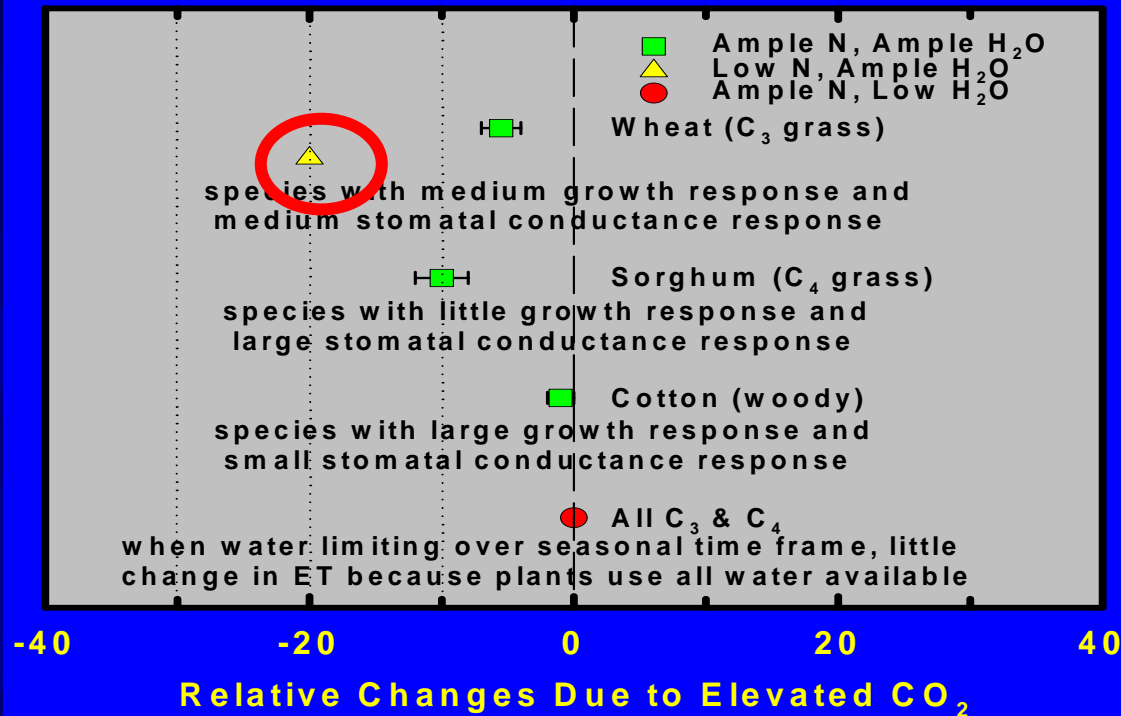


(Kimball, Kobayashi, Bindi, 2002)

What is the impact of climate change on agricultural systems ? (Potential Impact)

Water relations

Water Relations: Evapotranspiration



Evapotranspiration:

- Reduction up to -20% (wheat)
- More evident under nutrient shortage

(Kimball, Kobayashi, Bindi, 2002)

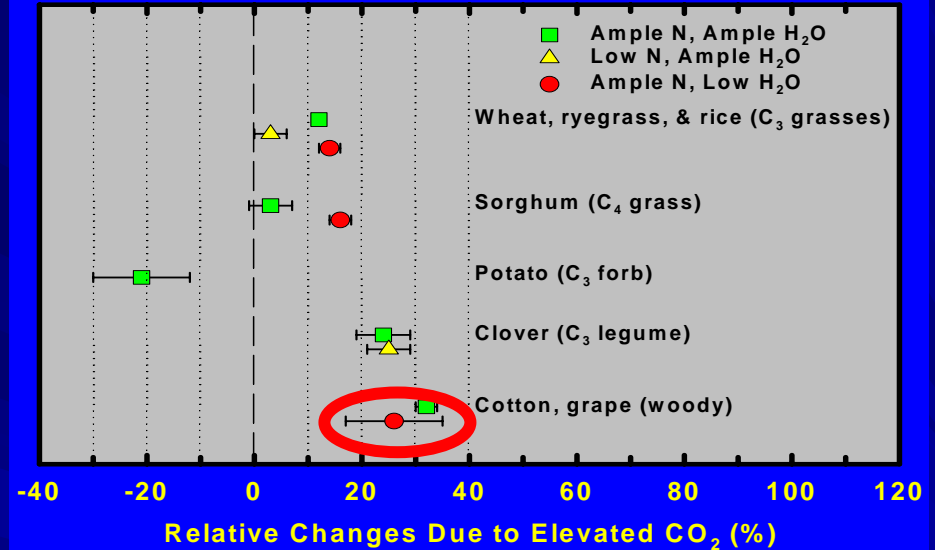
What is the impact of climate change on agricultural systems? (Potential Impact)

Biomass Accumulation

Above ground:

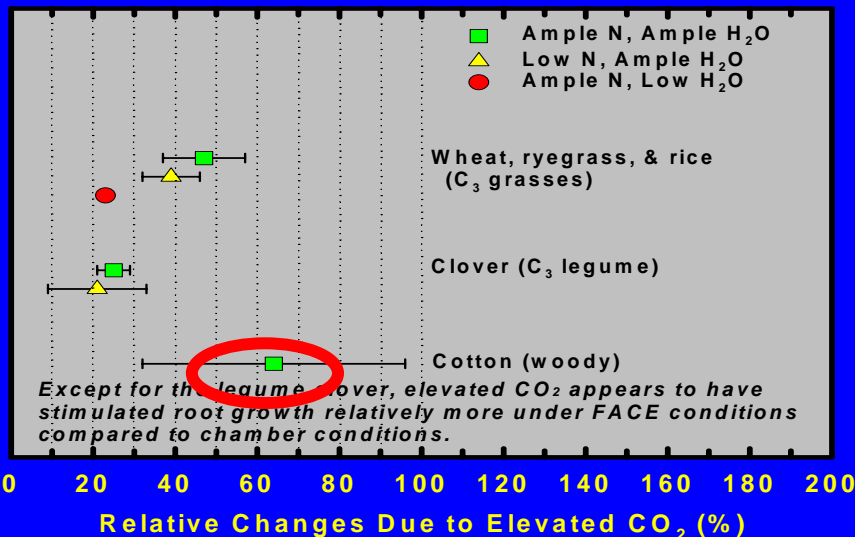
- increases up to 30% (cotton and vine)

Biomass Accumulation: Shoots



(Kimball, Kobayashi, Bindi, 2002)

Biomass Accumulation: Roots



Below ground:

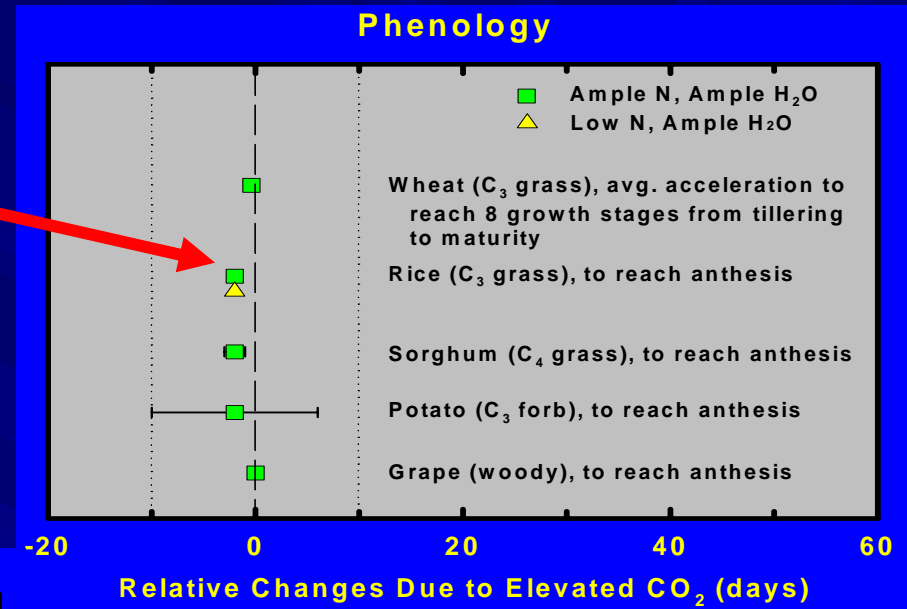
- increases up to +70% (cotton)

What is the impact of climate change on agricultural systems ? (Potential Impact)

Biomass Accumulation

■ Phenology:

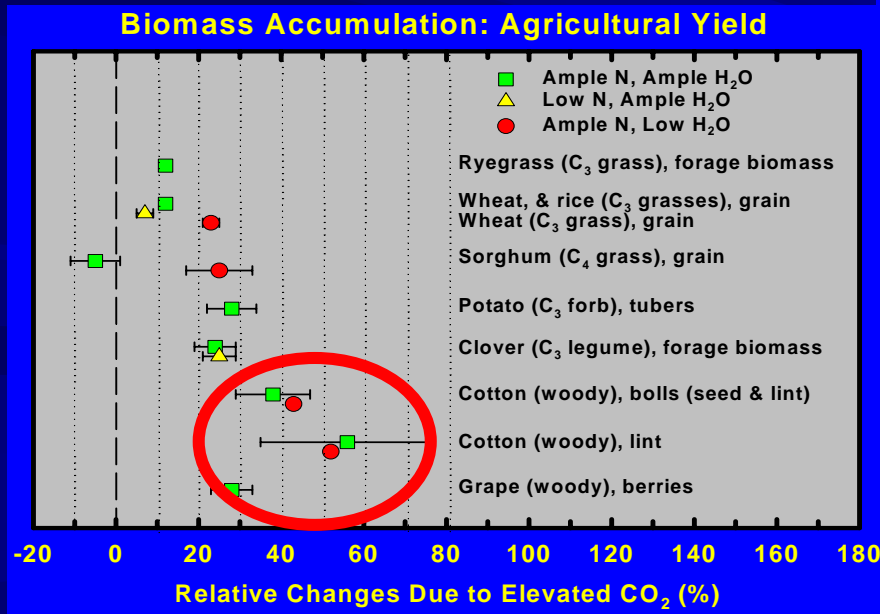
- No changes (-1/+2%)



(Kimball, Kobayashi, Bindi, 2002)

■ Yield:

- General increases (+30-55%)



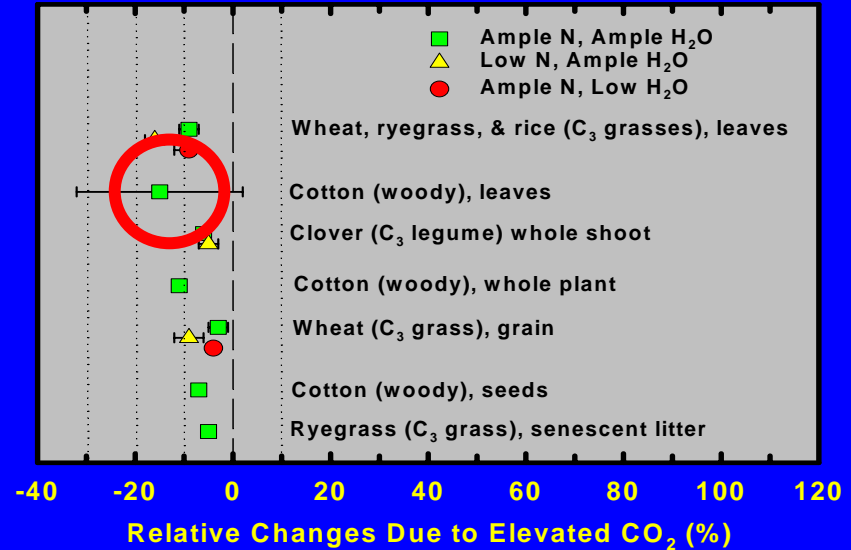
What is the impact of climate change on agricultural systems ? (Potential Impact)

Chemical composition of yield

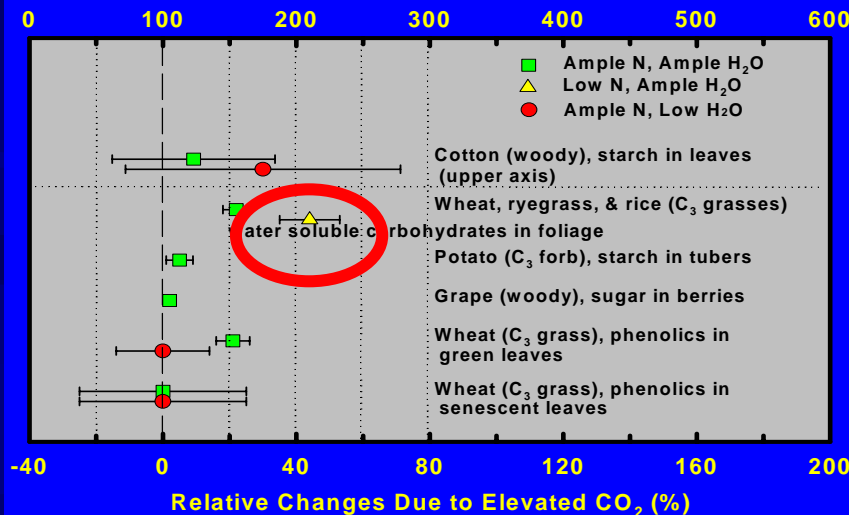
■ N concentration:

- Reduction mainly at leaf level

Chemical Composition Changes: N Concentration



Chemical Composition Changes: Carbohydrates and other C-based compounds



(Kimball, Kobayashi, Bindi, 2002)

■ C concentration:

- Strong increase in carbohydrates and other C components

What is the impact of climate change on agricultural systems ? (Potential Impact)

Indirect Impact

Change in climate parameters

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graph LR; A[Change in climate parameters] --- B[Suitable area for cultivation]; A --- C[Phenology]; A --- D[Yield];
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**Suitable area
for cultivation**

Phenology

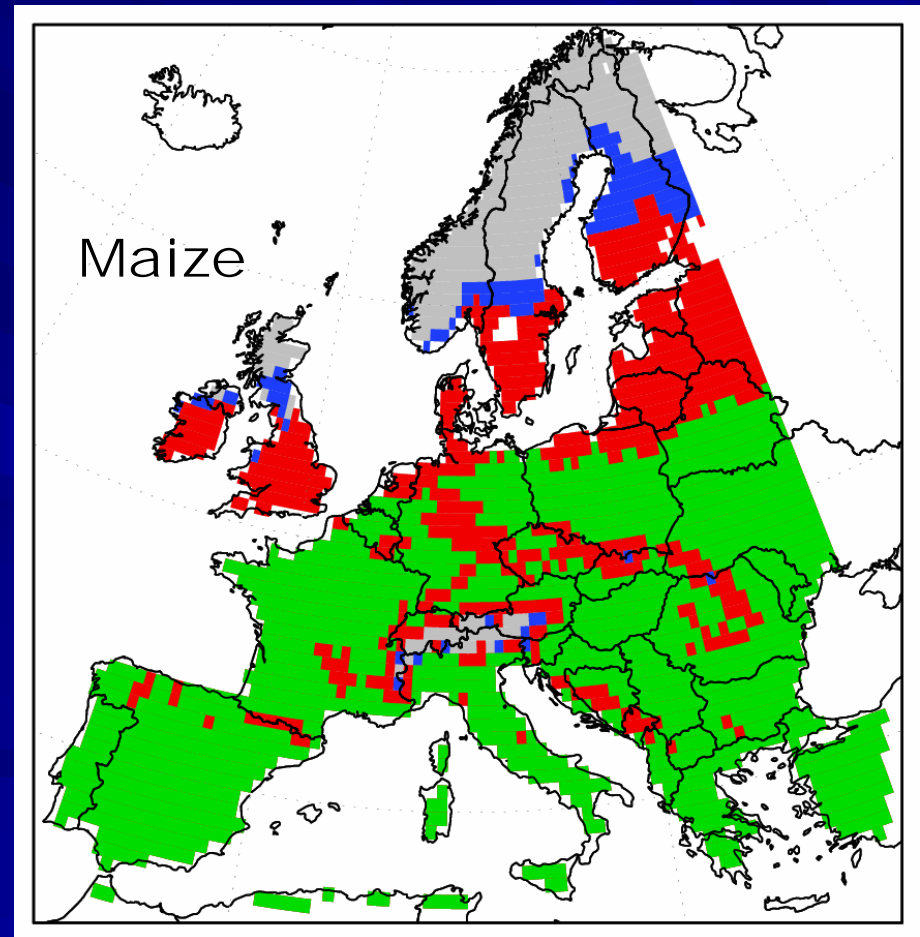
Yield

What is the impact of climate change on agricultural systems ? (Potential Impact)

Indirect Impact (Suitable area for cultivation)

Arable crops currently grown in the southern Europe will become suitable for the cultivation in northern European countries or in higher altitude areas in the south (e.g. summer crops such as maize, sunflower and soybeans)

- Present suitable area
- Expansion of suitable area
- Uncertain suitable area
- Unsuitable areas



From Olesen et al., 2005

What is the impact of climate change on agricultural systems ? (Potential Impact)

Indirect Impact (phenology, e.g. length of the growth season)

The predicted increases in temperature will determine a reduction of the length of the growing period

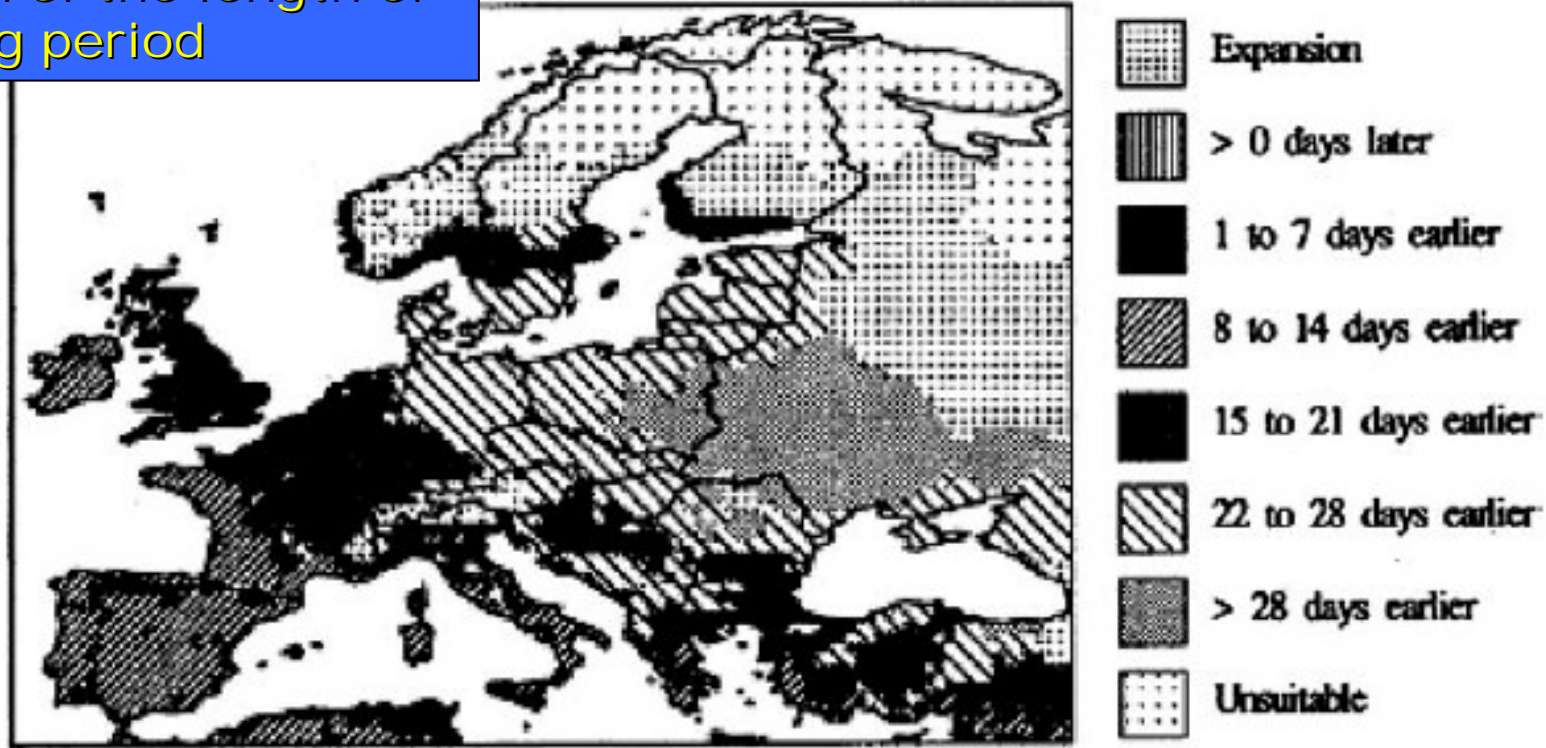
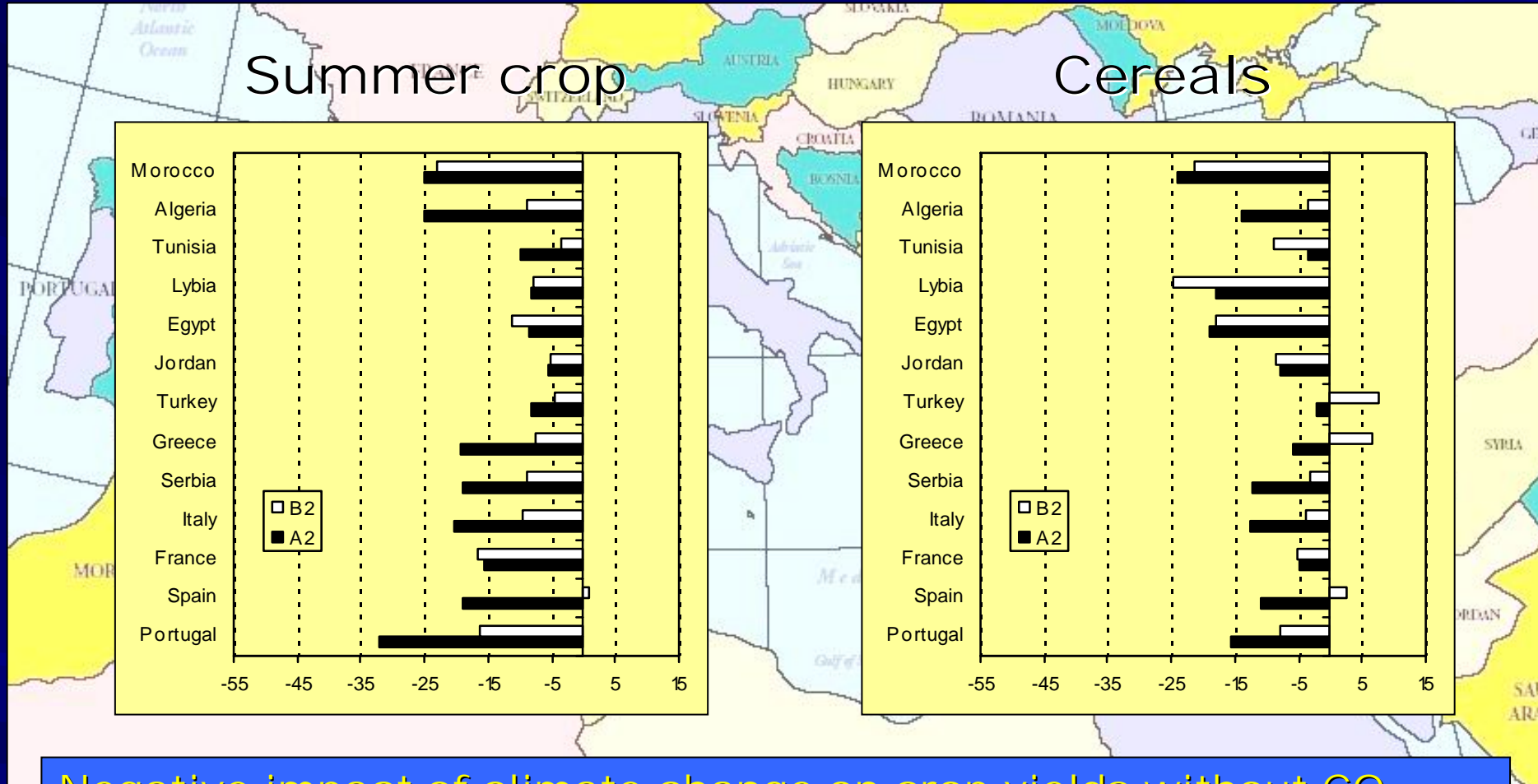


Figure 3. Change in the duration from sowing to maturity for winter wheat (cv. Avalon) under UK Transient scenario 2066-75 (from Harrison et al., 1995b).

What is the impact of climate change on agricultural systems ? (Potential Impact)

Indirect Impact (% changes in crop yields in the Med. region)

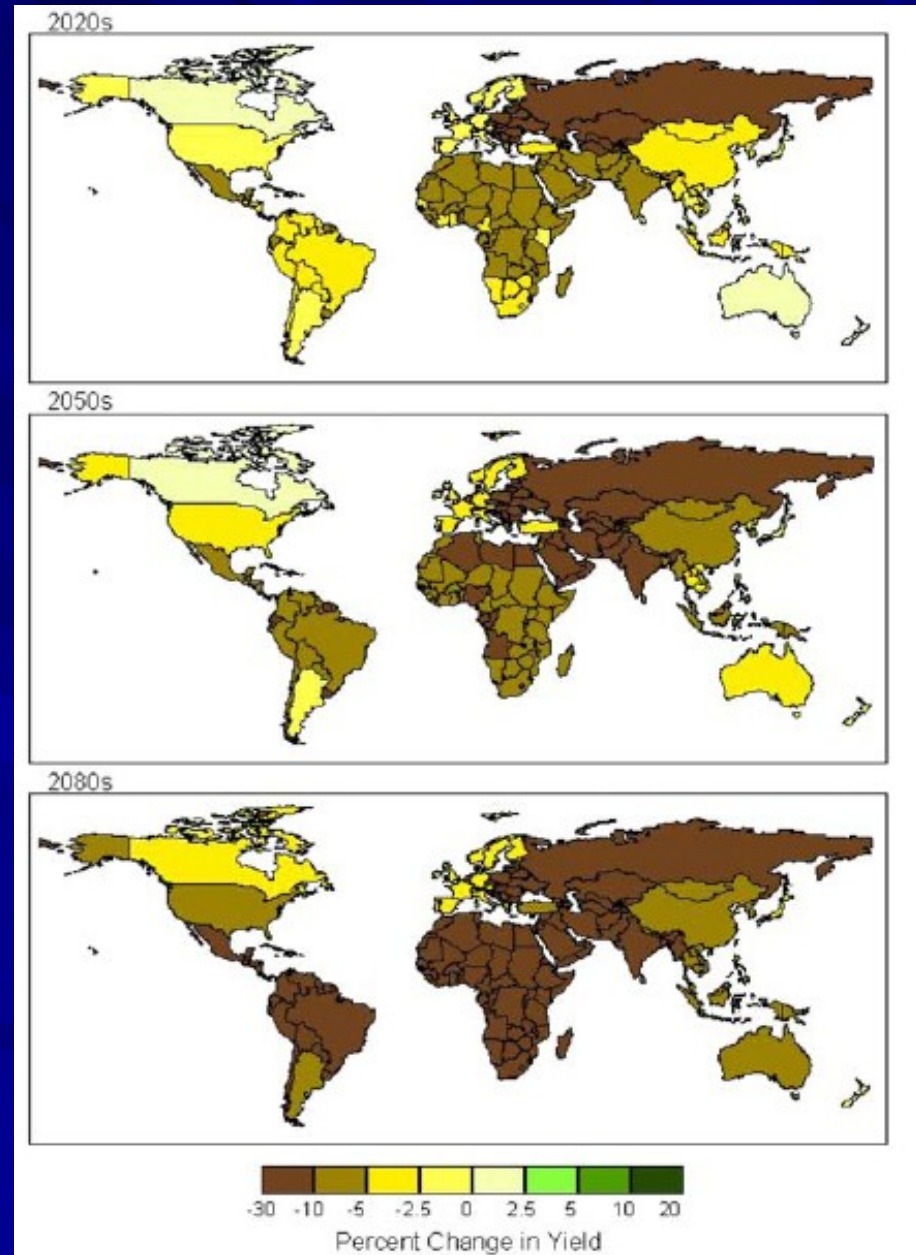


Negative impact of climate change on crop yields without CO₂ effect under HadCM3 - 2031-2060 (2° C global temperature rise)
(from Giannakopoulos et al., 2005 for WWF-Report).

What is the impact of climate change on agricultural systems ? (Potential Impact)

Indirect Impact (yield)

Prevalent negative impact of climate change on cereal yields without CO₂ effect under HadCM3 - A2 scenario (from Parry et al., 2004).



What is the impact of climate change on agricultural systems ? (Potential Impact)

Direct + Indirect Impact

**CO₂ increase and
changes in climate**

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graph LR; A[CO2 increase and changes in climate] --- B[Mean Yield]; A --- C[Yield variability]; A --- D[Yield quality];
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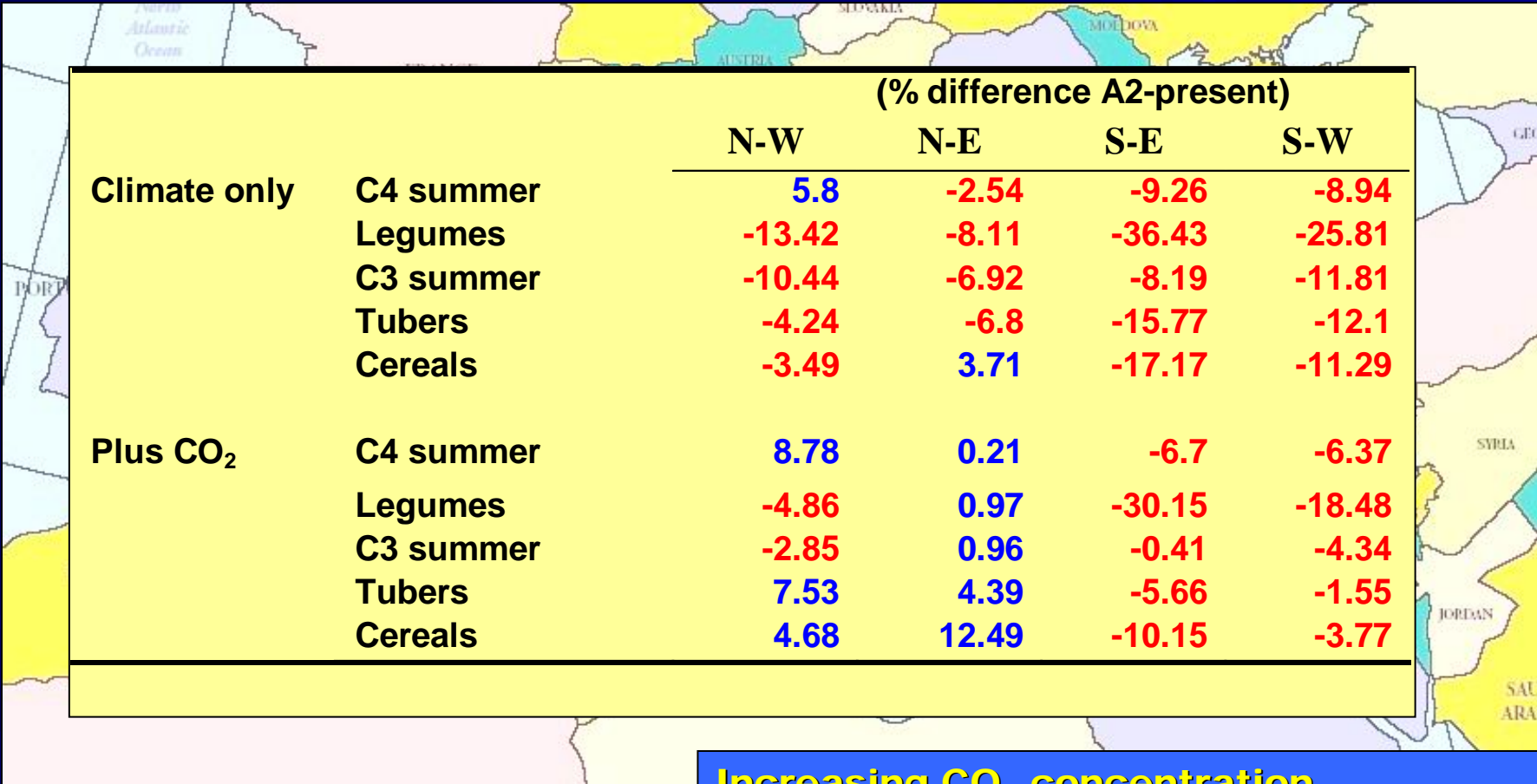
Mean Yield

Yield variability

Yield quality

What is the impact of climate change on agricultural systems ? (Potential Impact)

Combined impact (mean yield): at Regional Level



		(% difference A2-present)			
		N-W	N-E	S-E	S-W
Climate only	C4 summer	5.8	-2.54	-9.26	-8.94
	Legumes	-13.42	-8.11	-36.43	-25.81
	C3 summer	-10.44	-6.92	-8.19	-11.81
	Tubers	-4.24	-6.8	-15.77	-12.1
	Cereals	-3.49	3.71	-17.17	-11.29
Plus CO ₂	C4 summer	8.78	0.21	-6.7	-6.37
	Legumes	-4.86	0.97	-30.15	-18.48
	C3 summer	-2.85	0.96	-0.41	-4.34
	Tubers	7.53	4.39	-5.66	-1.55
	Cereals	4.68	12.49	-10.15	-3.77

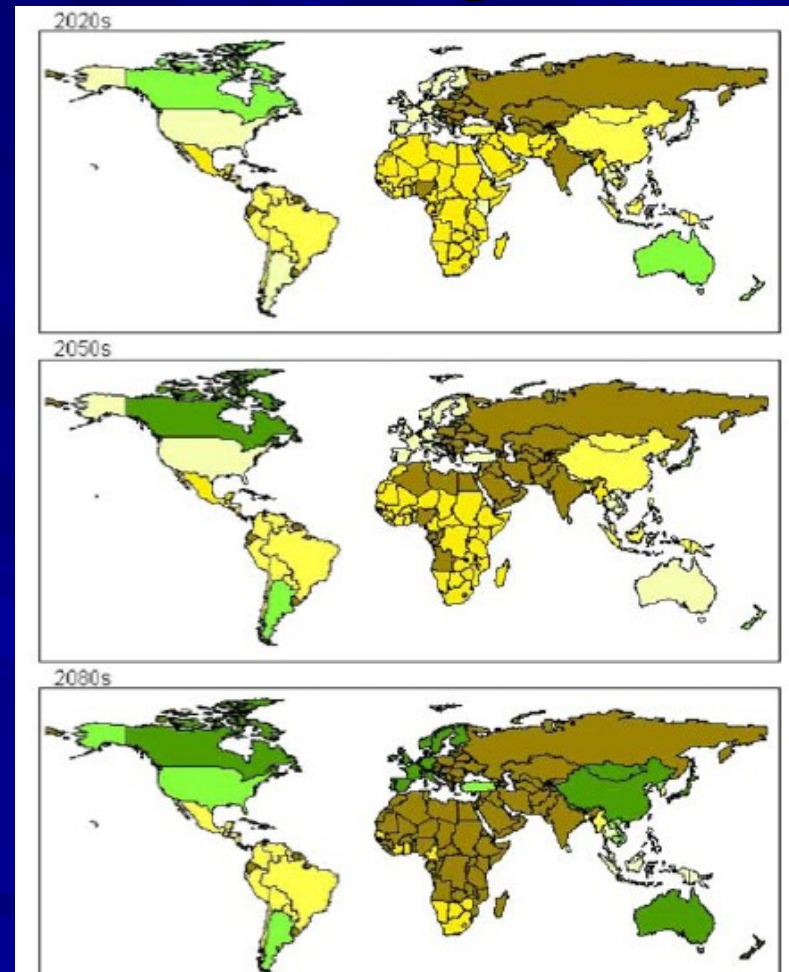
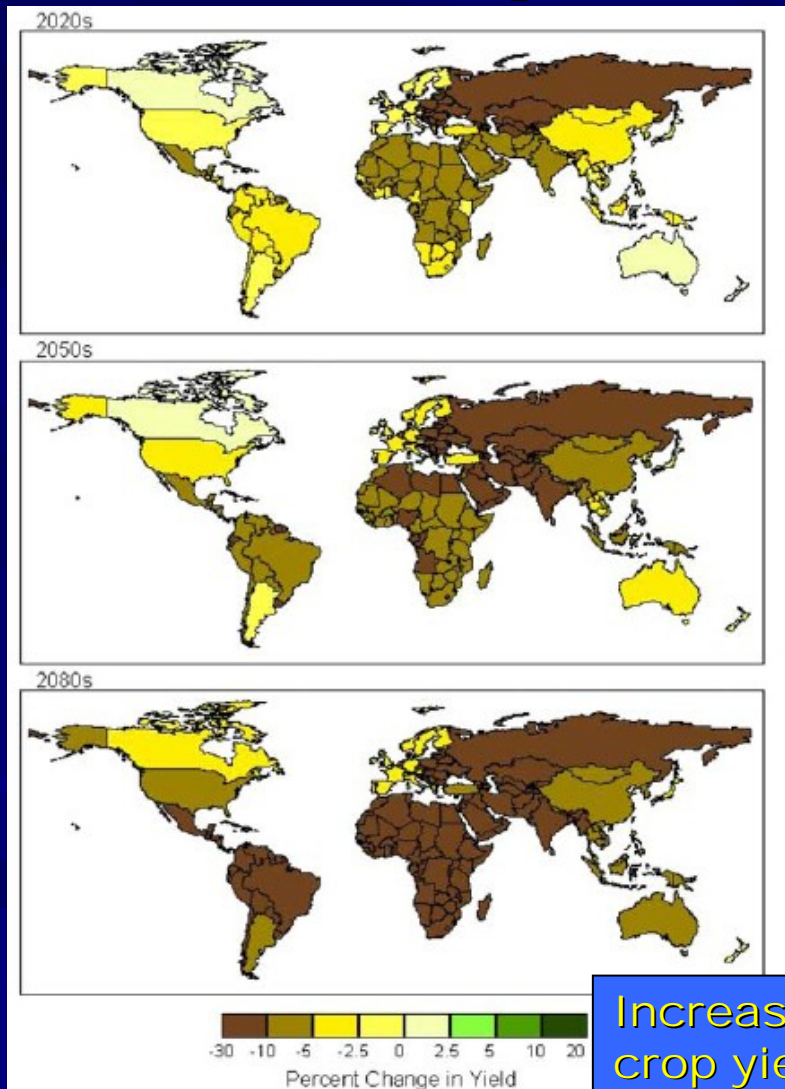
Increasing CO₂ concentration ameliorates crop yield loss and improves gain in some cases

What is the impact of climate change on agricultural systems ? (Potential Impact)

Combined impact (mean yield): at Global scale

Without CO₂

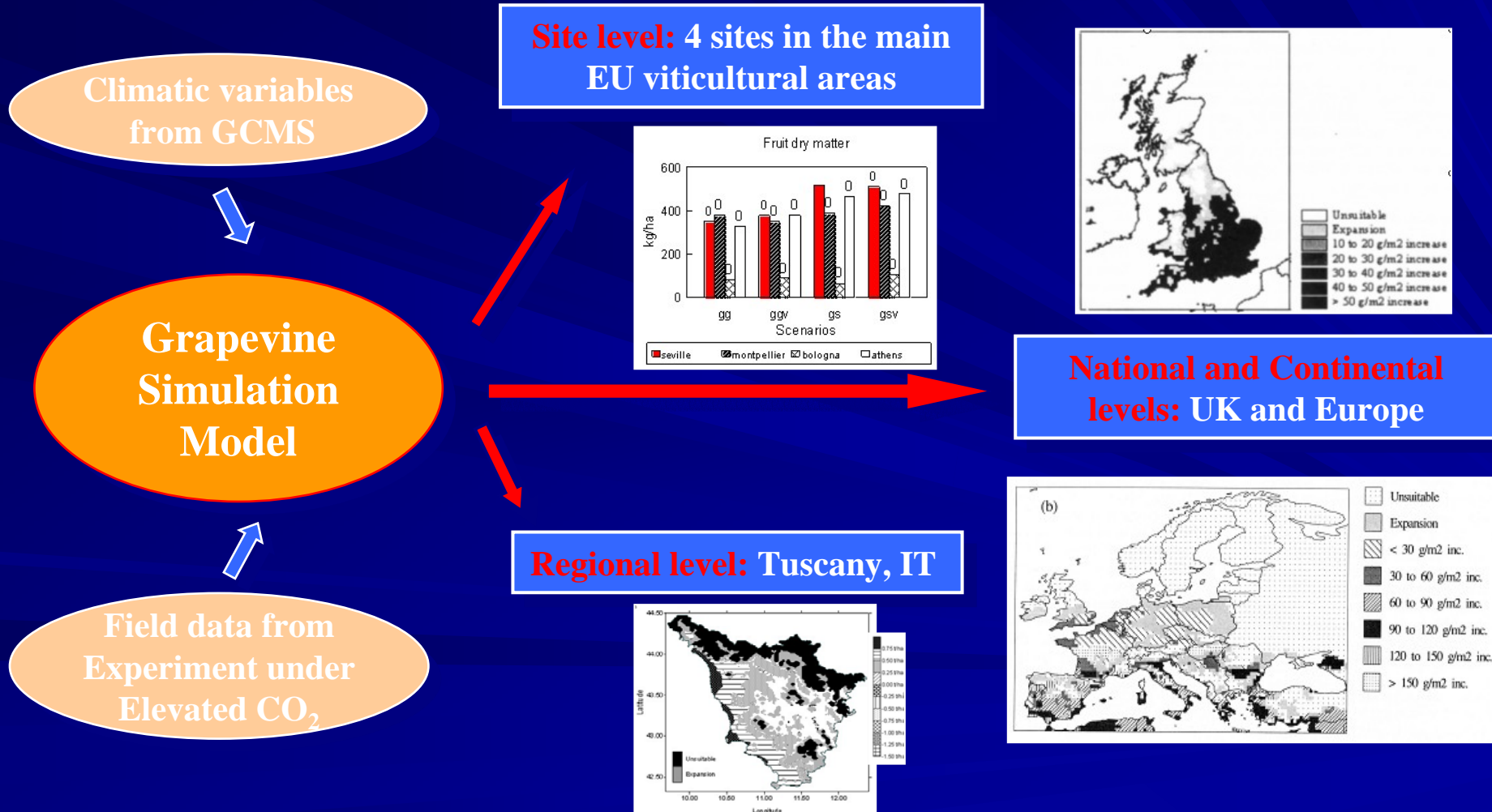
With CO₂



Increasing CO₂ concentration allows an increase crop yield in very important agricultural areas (North America, China, Australia).

What is the impact of climate change on agricultural systems? (Potential Impact)

Combined impact (mean yield, yield quality and yield variability): A few studies have carried out to investigate the impact on all the three components of crop yield



Example for grapevine (Bindi et al., 1999 and Harrison et al., 1999)

What is the impact of climate change on agricultural systems ? (Potential Impact)

Grapevine yield

Site level

- AVG in grapes yield: ↑ (n.s.)
- AVG in grapes quality: ↓ (n.s.)
- CV in grapes yield and quality: ↑ (P<0.05)

Regional level

- AVG in grapes yield: ↑ (small)
- AVG in grapes quality: ↓ (small)
- CV in grapes yield and quality: ↑ (high)

National and Continental level

- AVG in grapes yield: ↑ (larger in Southern UK and Southern Europe)

n.s.= not significant, s.s.= statistically significant;
Future - Present = ↑ increase, ↔ no difference, ↓ decrease

What is the impact of climate change on agricultural systems ?
(Potential Impact)

Answer

Climate change may strongly affect agricultural systems through potential impacts on:

- Ecophysiological processes regulating crop growth (e.g. photosynthesis, transpiration, etc.)
 - Suitable area for crop cultivation
- Yield quantity and quality (mean and variability)

How can agricultural systems adapt to a changing climate ?
(Adaptive capacity)

Adaptation strategies:

- **The social/economic strategies** are intended to render the agricultural costs of climate change small
- **The agronomic and crop strategies** are intended to offset either partially or completely the loss of productivity caused by climate change through the application of defense tools with different:
 - **temporal scales**, e.g. short term adjustments and long term adaptations
 - **spatial scales**, e.g. farm, regional or national level adaptation

How can agricultural systems adapt to a changing climate ? (Adaptive capacity)

Agronomic and crop adaptations

Short-term adjustments - first defense tools to optimise production with minor system changes through:

- *The management of cropping systems (reduce yield variability)*
 - *Changes in crop varieties* (different thermal requirements and lower yield variability)
 - *Changes in agronomic practices* (sowing/planting dates)
 - *Changes in fertiliser and pesticide use*
 - *Adoption of new tools for crop selection* (climate seasonal forecasts)
- *The conservation of soil moisture (reduce drought stress and irrigation requirements)*
 - *Introduction of moisture conserving tillage methods* (minimum tillage, conservation tillage, stubble mulching etc.)
 - *Management of irrigation* (amount and efficiency)

How can agricultural systems adapt to a changing climate ? (Adaptive capacity)

Agronomic and crop adaptations

Long-term adaptation - complementary defense tools to optimise production via larger structural system changes:

- ***Changes in land allocation*** to optimise or stabilise production
- ***Development of "designer-cultivars"*** to rapidly adapt to climate change stresses (heat, water, pest and disease, etc.)
- ***Crop substitution*** to conserve soil moisture (e.g. sorghum is more tolerant of hot and dry conditions than maize)
- ***Microclimate modification*** to improve water use efficiency in agriculture (e.g. windbreaks, intercropping, multi-cropping techniques)
- ***Changes in nutrient management*** to reflect the modified growth and yield of crops

How can agricultural systems adapt to a changing climate ? (Adaptive capacity)

Agronomic and crop adaptations

Regional change (%) in crop production and GDP under UKMO-GCM scenario

Regions	Crop prod.	GDP
Developed		
Climate effects only	-18.6	-28.9
Plus physiological effect of CO ₂	-2.1	-9.8
Plus adaptation level 1	+5.0	-3.6
Plus adaptation level 2	+6.4	+0.8
Developing		
Climate effects only	-27.1	-35.1
Plus physiological effect of CO ₂	-4.5	-13.0
Plus adaptation level 1	-3.9	-12.3
Plus adaptation level 2	-0.8	-5.6

Source: Rosenzweig and Parry, 1994.

Adaptation Level 1:

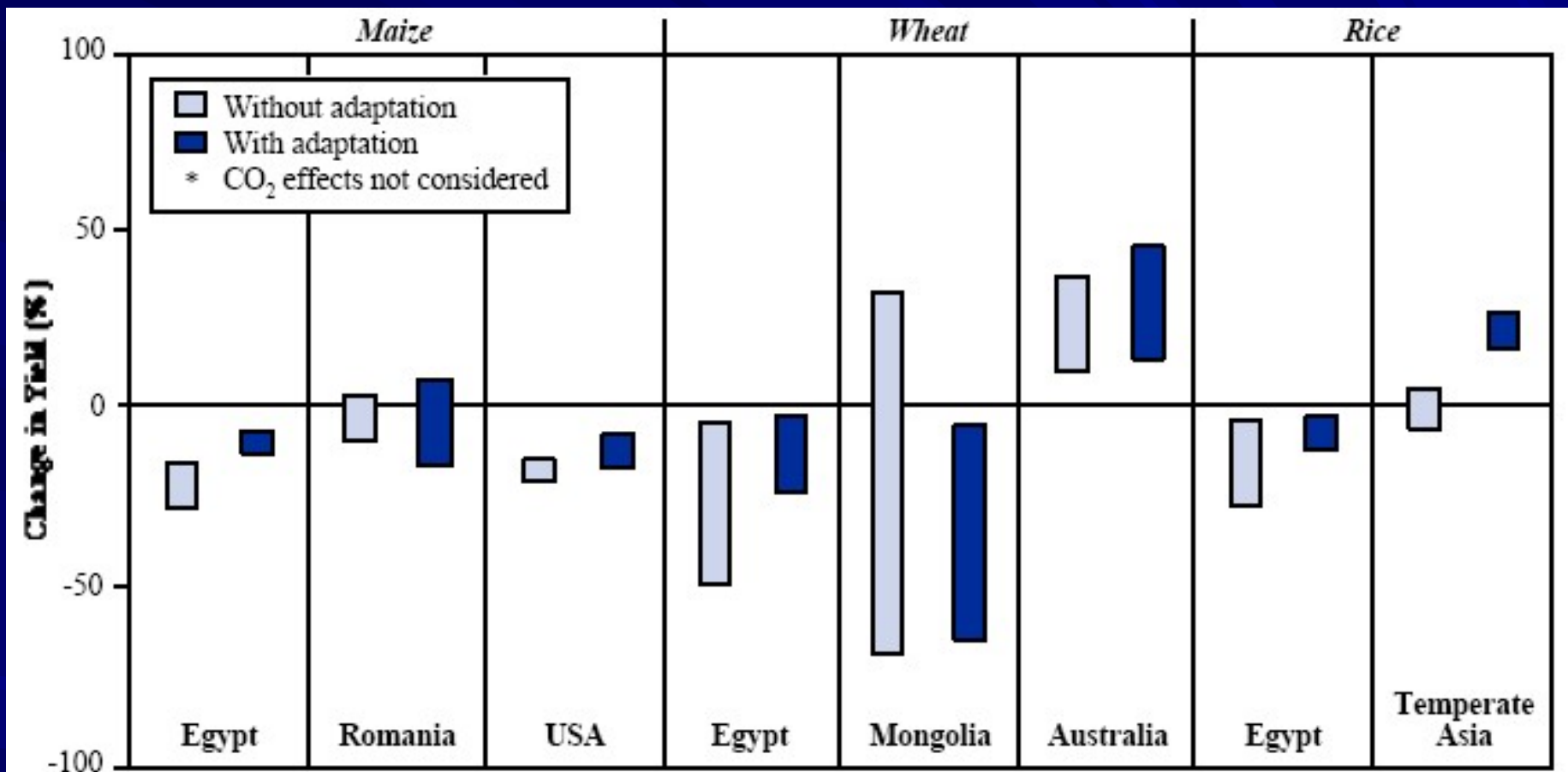
- *shifts in the planting date* of less than 1 month
- *additional water* for crops already irrigated
- *change in crop varieties*

Adaptation Level 2:

- *shifts in the planting date* of more than 1 month
- *increase fertiliser application*
- *installation of irrigation*
- *new crop varieties*

How can agricultural systems adapt to a changing climate ? (Adaptive capacity)

Agronomic and crop adaptations



From TAR-IPCC, 2001

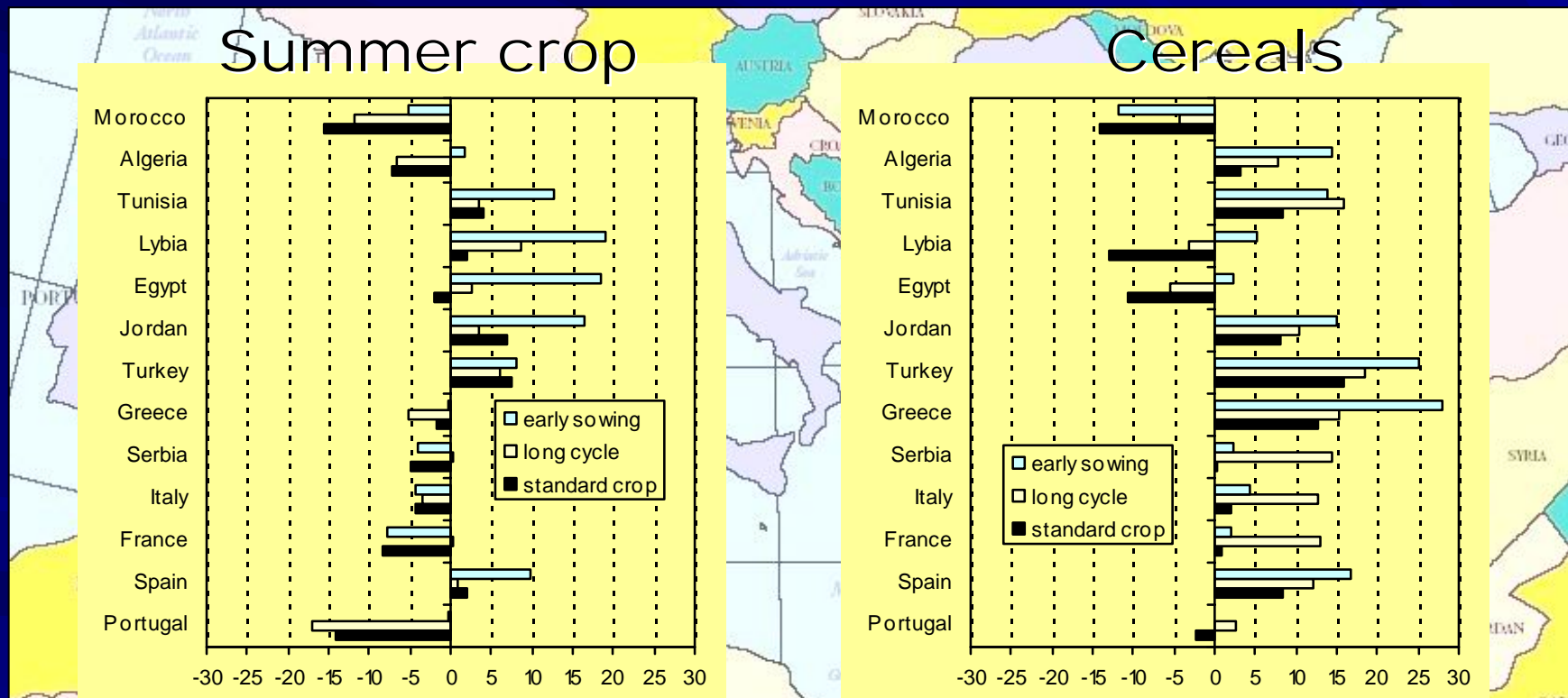
Autonomous agronomic adaptation ameliorates temperate crop yield loss and improves gain in most cases, but in tropical areas crop yields tend to remain below baseline levels

How can agricultural systems adapt to a changing climate ? (Adaptive capacity)

Agronomic and cultural adaptations

Adaptation Level:

- *shifts in the planting date (early or late)*
- *change in crop varieties (longer or shorter growing cycle)*



Early sowing and varieties with longer growing cycle ameliorates crop yield loss and improves gain in most cases (Giannakopoulos et al., 2005)

How can agricultural systems adapt to a changing climate ?
(Adaptive capacity)

Answer

Agronomic and crop adaptation strategies may be used to reduce losses or to increase gains due potential impact of climate change

What is the vulnerability of agricultural systems under future climate change ?

Vulnerable components:

- Mean yields of C₄ crop yield and summer crops (summer drought and heat waves)
- Inter-annual variability of crop yields (increase in climate extreme events)
- Yield quality (drought stresses)
- Interaction with pest/diseases (higher winter temperature)
- Competition with weeds (higher CO₂ concentration)

What is the vulnerability of agricultural systems under future climate change ?

Vulnerable regions:

Northern and southern current marginal areas of Europe seem to be particularly vulnerable to climate changes

■ *Northern areas*

- increase in plant protection
- increase in risk of nutrient leaching
- acceleration of breakdown of soil organic matter

■ *Southern areas*

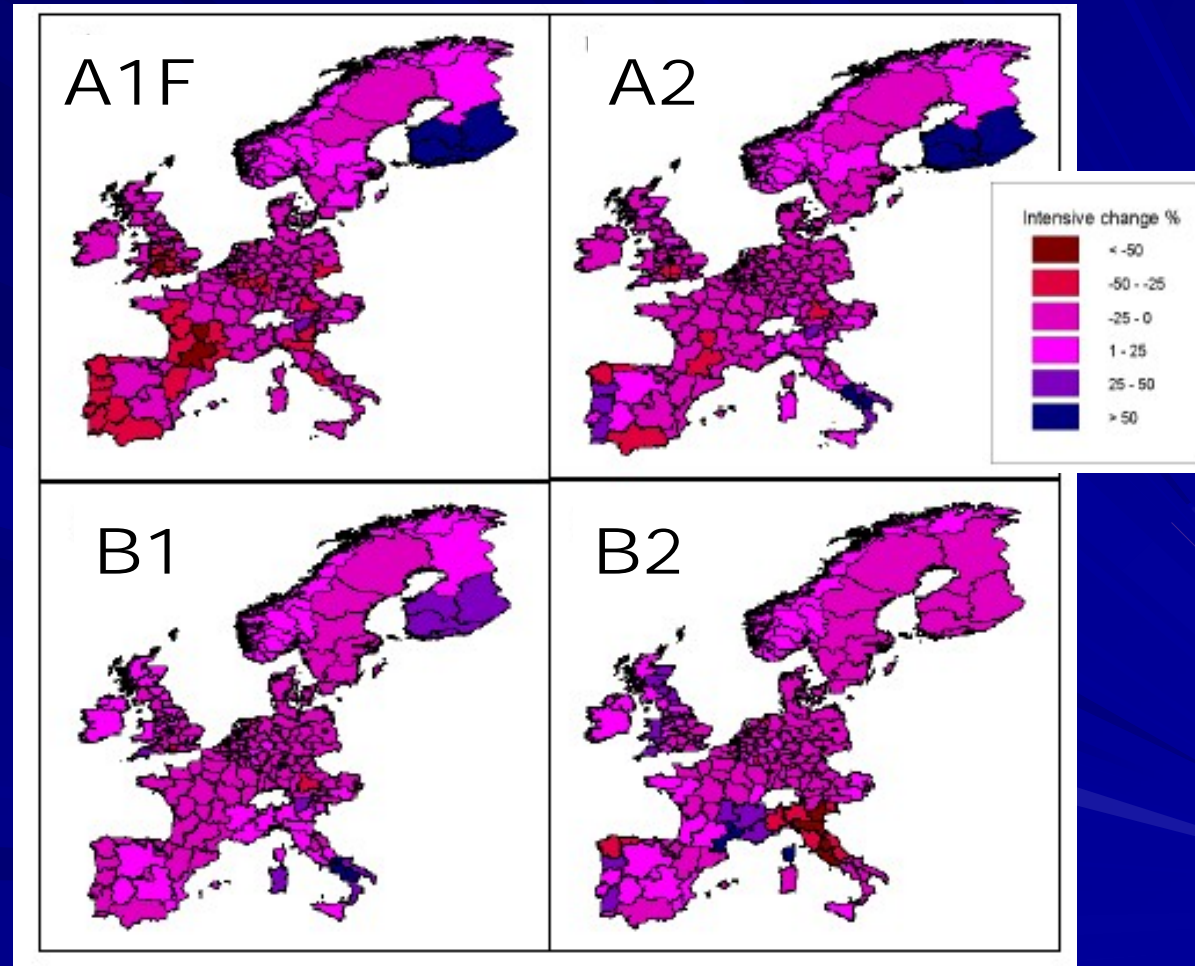
- lower yield
- higher yield variability
- reduction of suitable areas for traditional crops

How can agricultural systems adapt to a changing climate ? (Adaptive capacity)

(Examples of vulnerability of agriculture)

Farmers and environmental vulnerability:

- Intensification of land use in high latitude and altitude (impact on environment and biological resources)
- Extensification and abandonment of land use in low latitude (impact on farmer profits)

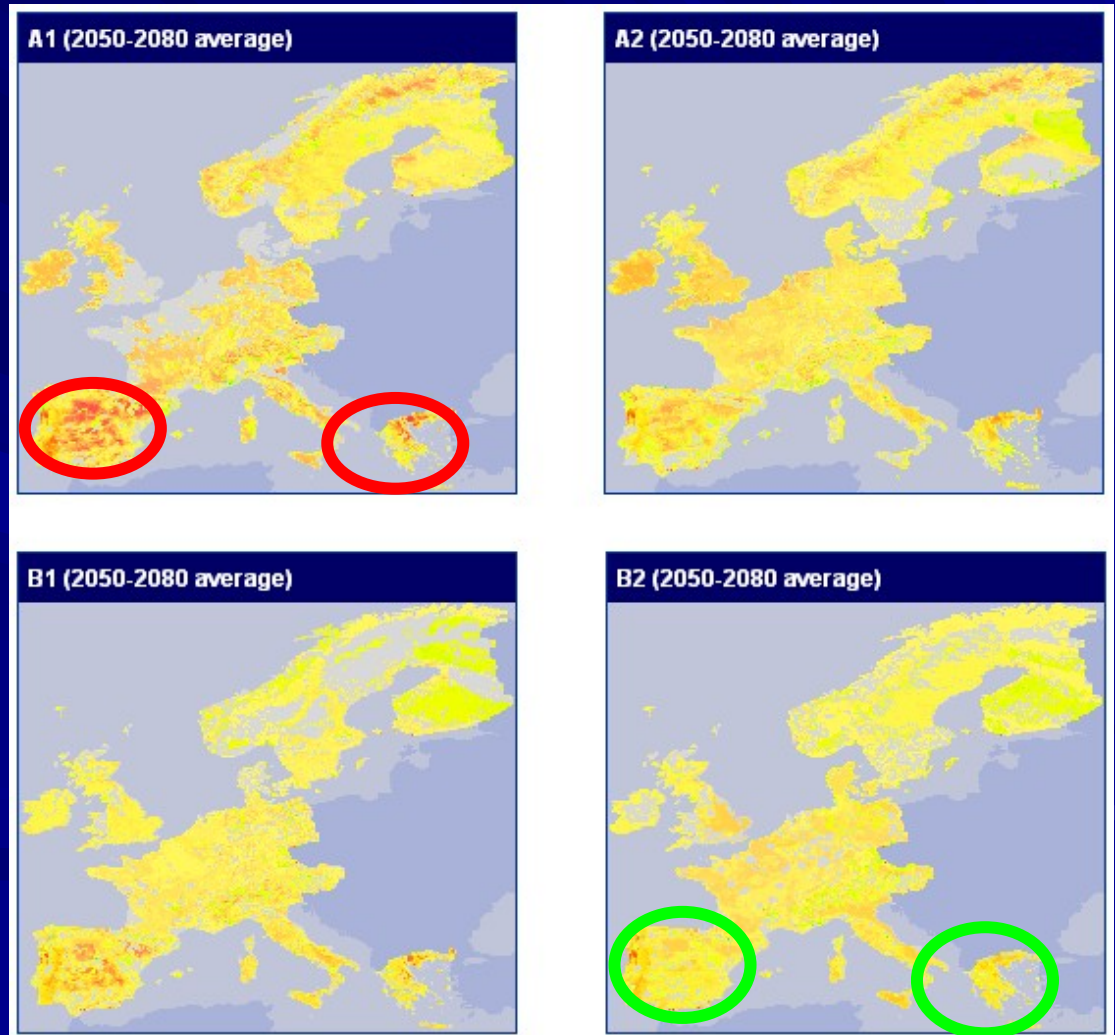
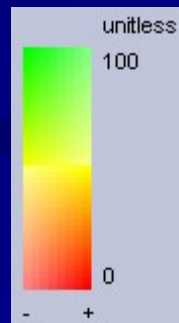


How can agricultural systems adapt to a changing climate ? (Adaptive capacity)

(Examples of vulnerability of agriculture)

Farmers livelihood (profits):

- Higher vulnerability in the Mediterranean region (e.g. Iberian Peninsula, Greece)
- Under Industrial scenario (A1) the vulnerability is higher (B2 best scenario for farmers)



(from ATEAM final report, 2004)