# Environmental Plant Physiology
## Summary

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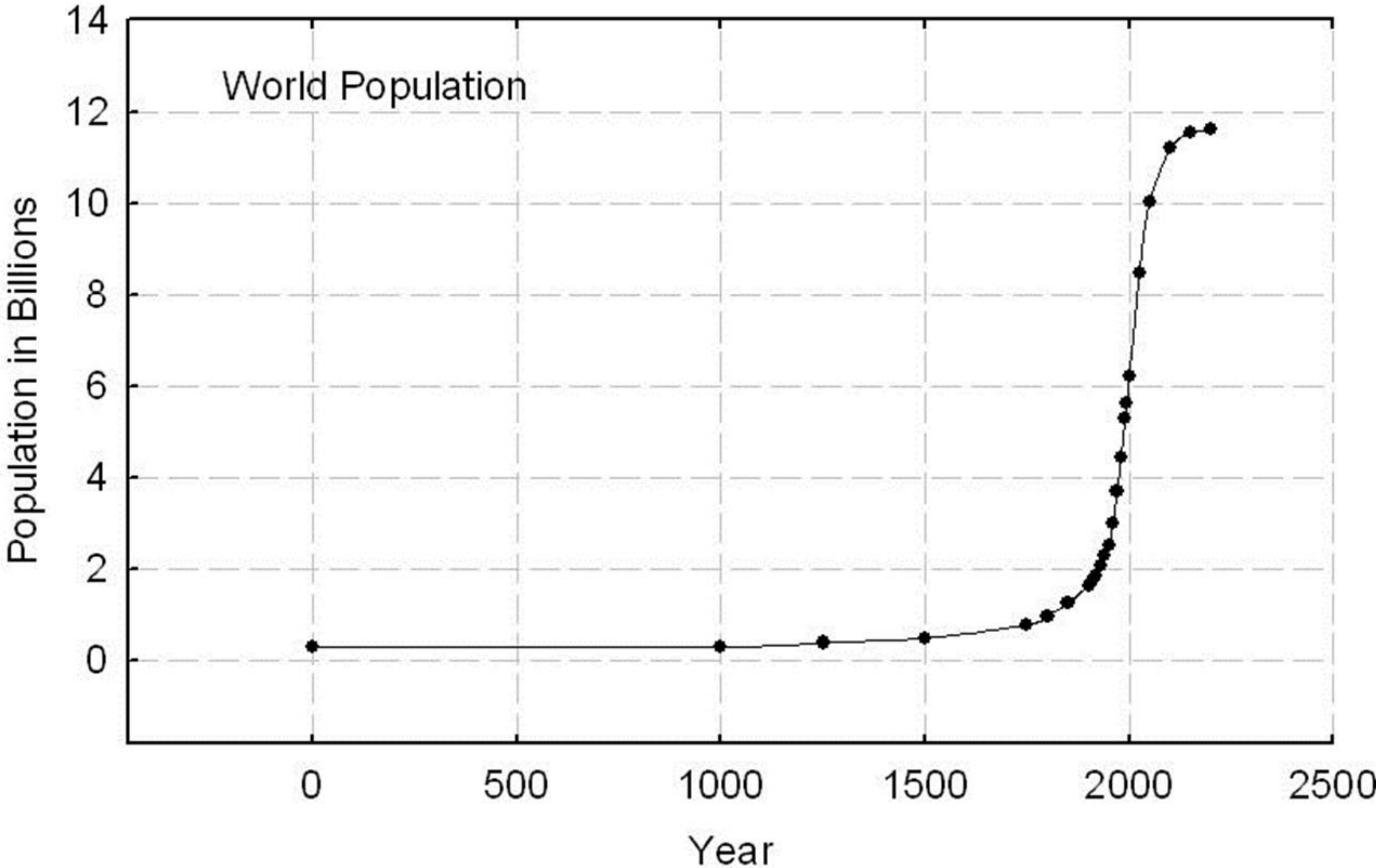
# Environmental Plant Physiology
## Objectives

- The objectives of this course were to learn plant responses to abiotic stresses, particularly plant growth and development, and to learn modeling methodologies on how to integrate those plant processes under multiple stress conditions.
- At the end, the students were expected to:
  - ✓ understand individual as well as interactive abiotic stress effects on photosynthesis, respiration, growth, development and finally yield.
  - ✓ understand on how to develop methodologies to integrate multiple stress factor effects on various plant/canopy processes.

# Trends That Shape Our Future

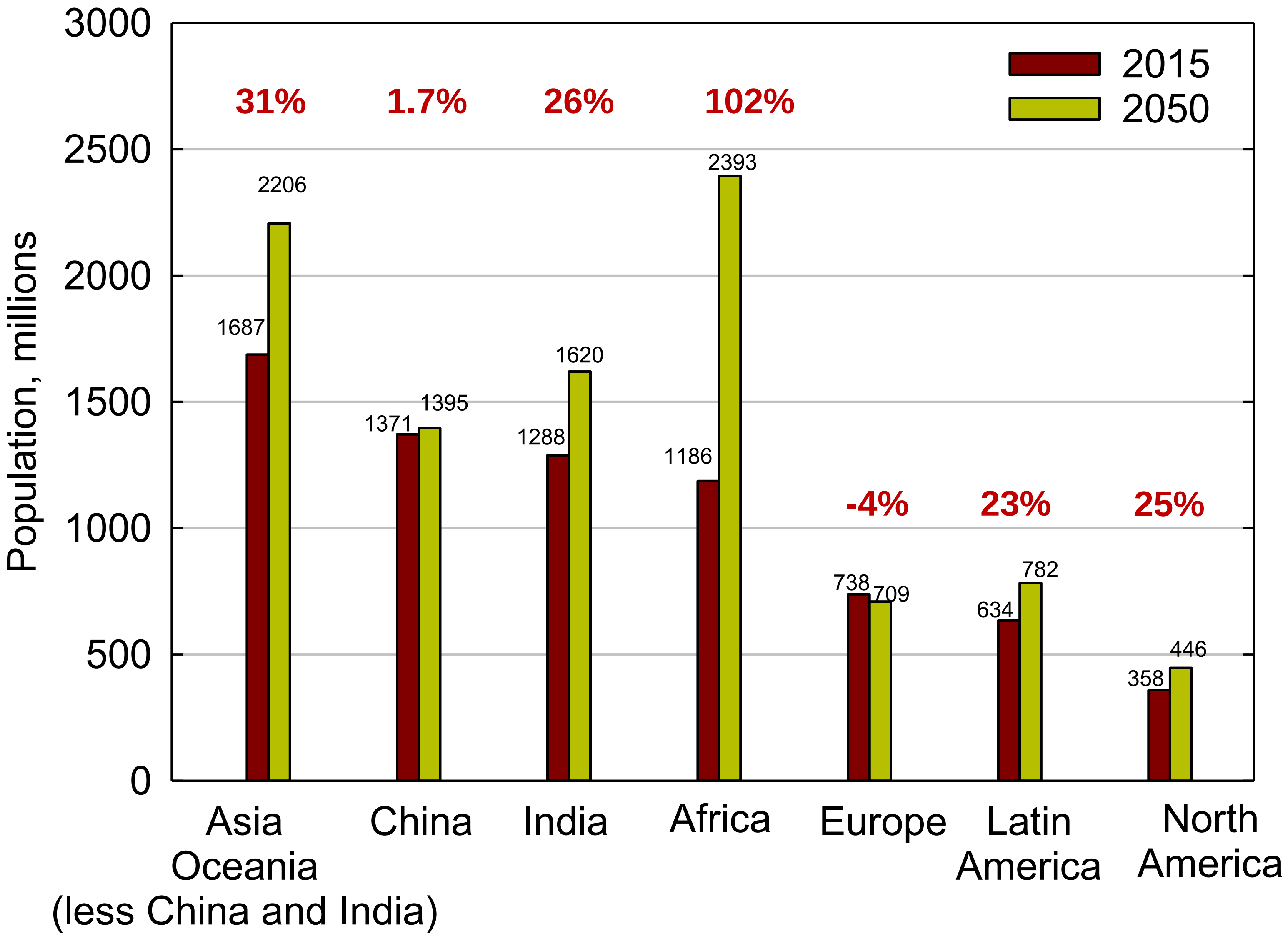
# Trends, Signs and Signatures from the Earth

## Past, Present and Future World Population



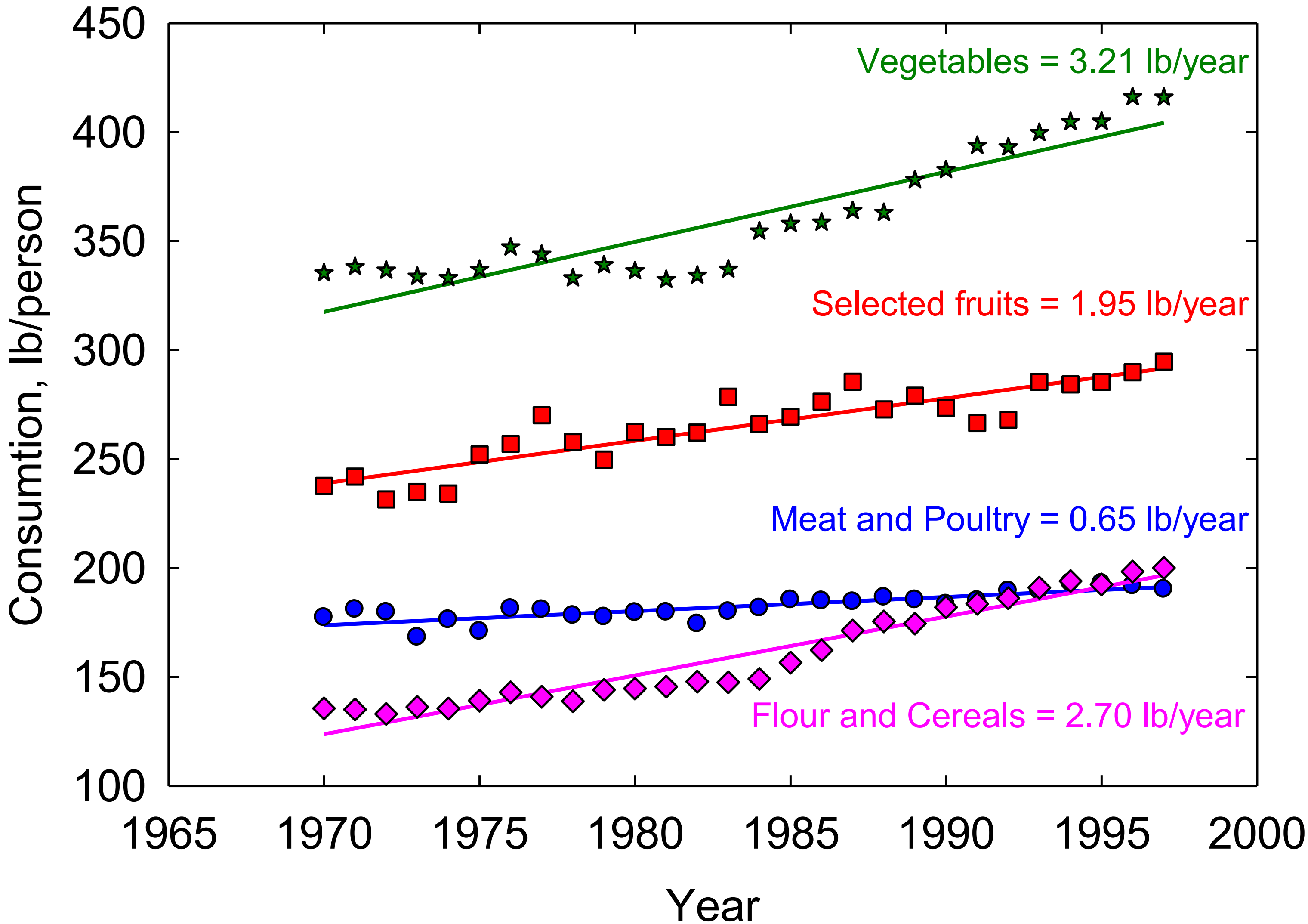
# Trends, Signs and Signatures from the Earth

## Present and Future World Population Trends



# Trends, Signs and Signatures from the Earth

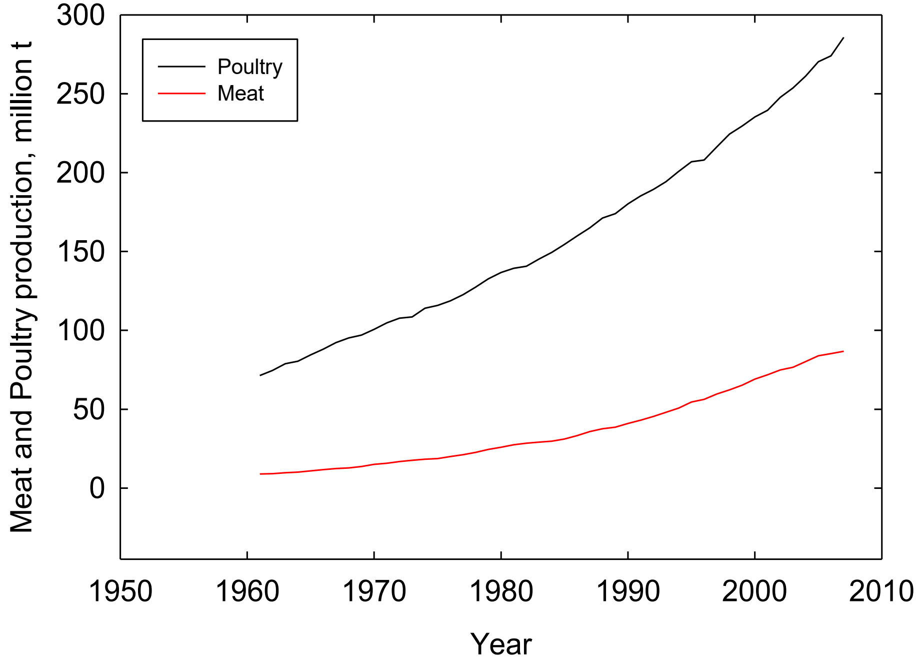
## Global Major Foods – Per Capita Consumption



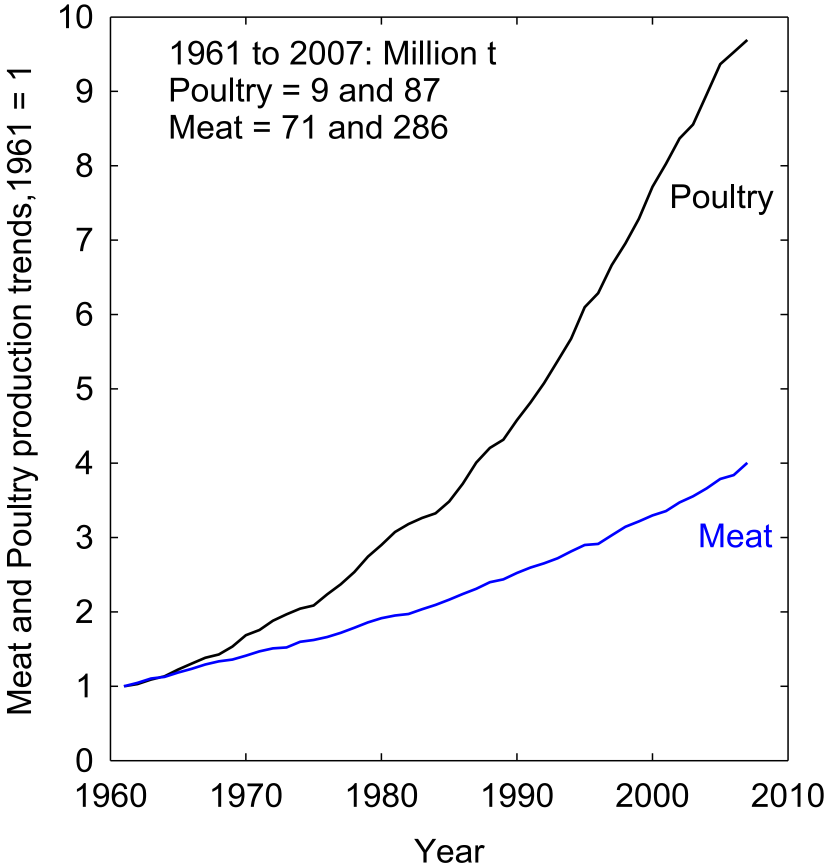
# Trends, Signs and Signatures from the Earth

## Global Major Foods – Meat and Poultry Production

### Meat and Poultry Production

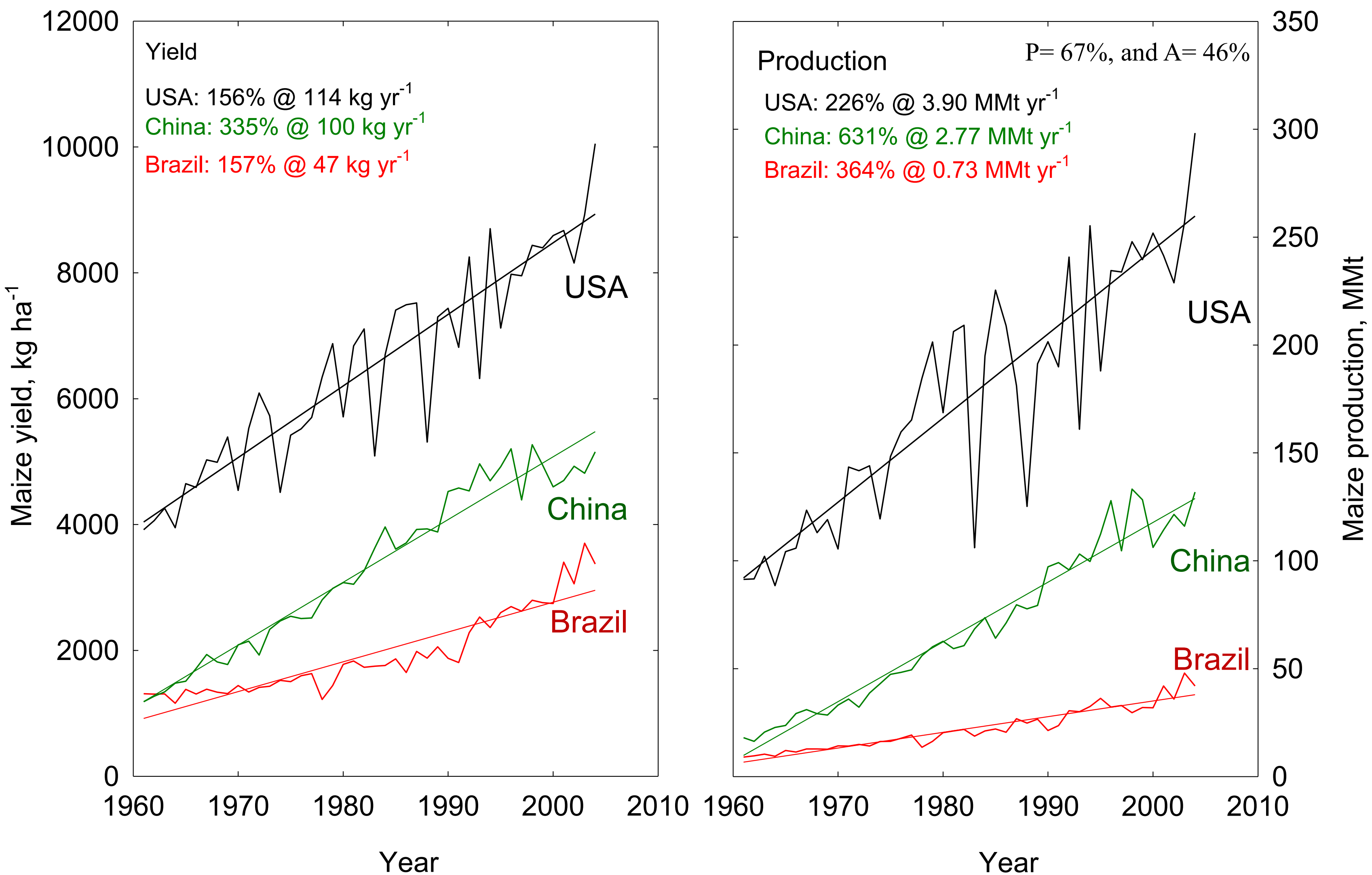



### Meat and Poultry Production
### Relative Trends



# Trends, Signs and Signatures from the Earth

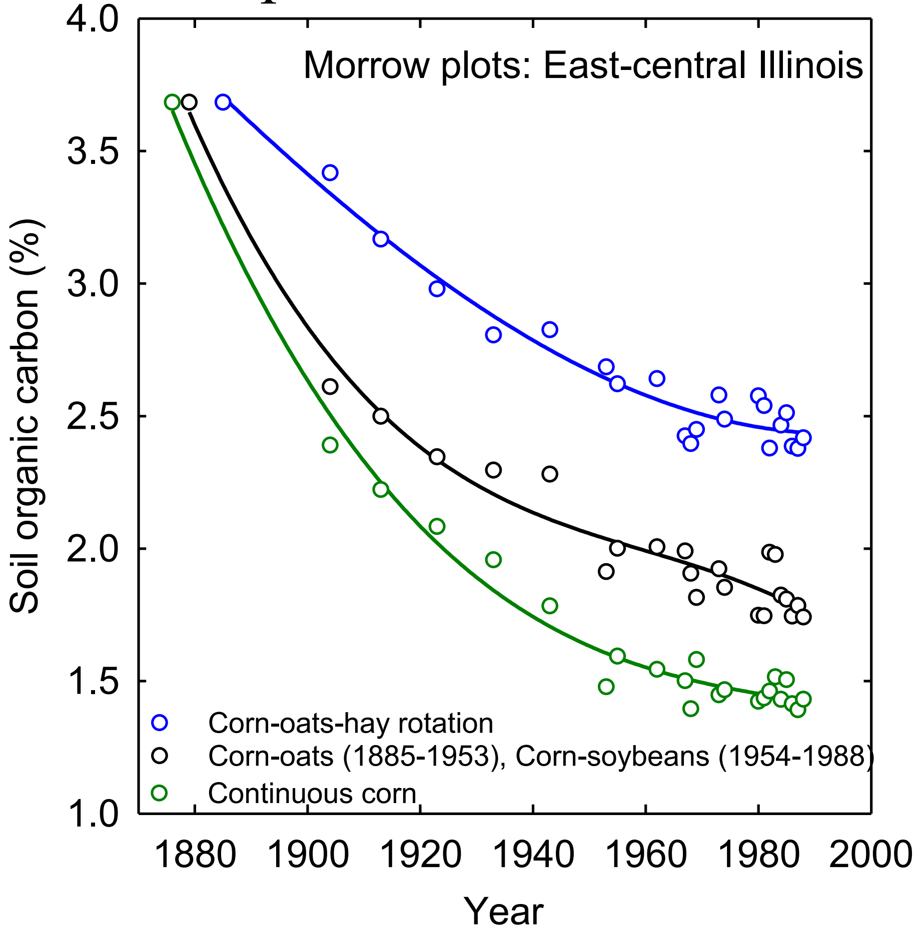
## Maize - Production and Yield – Selected Counties



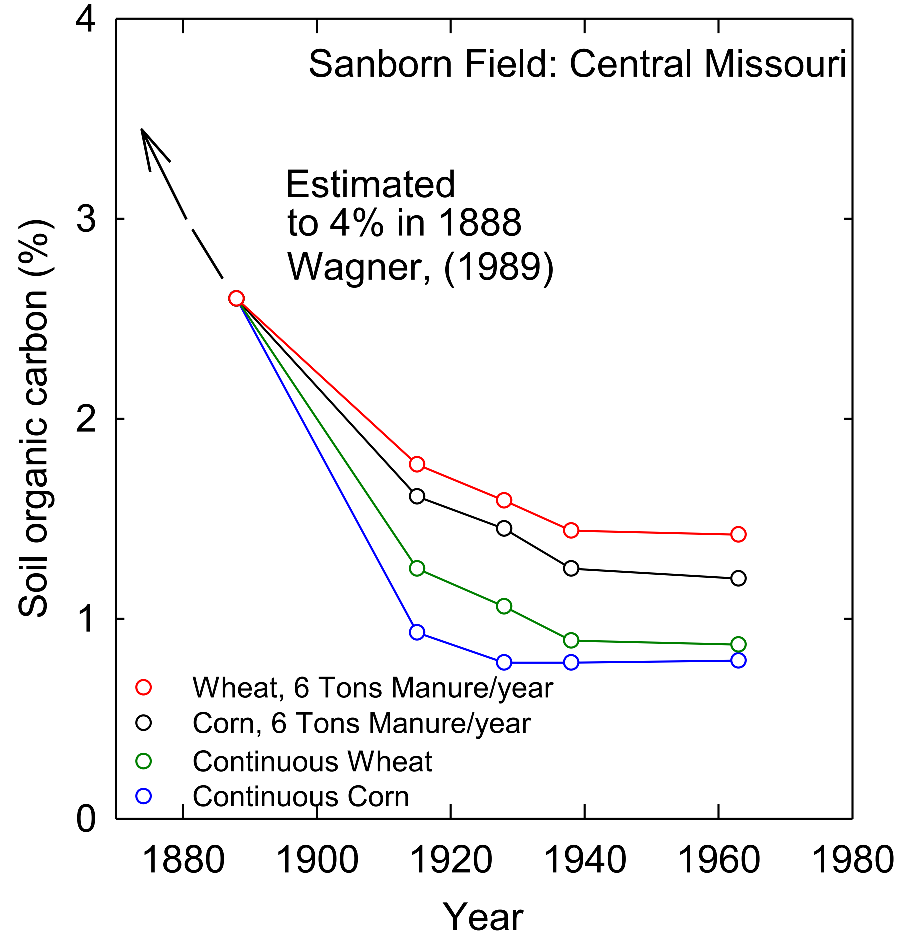
# Trends, Signs and Signatures from the Earth

## Management Practices

Crop rotations




Fertility management




Reicosky et al. 2000

# Trends, Signs and Signatures from the Earth

## Cropland area, Irrigation and Salinization

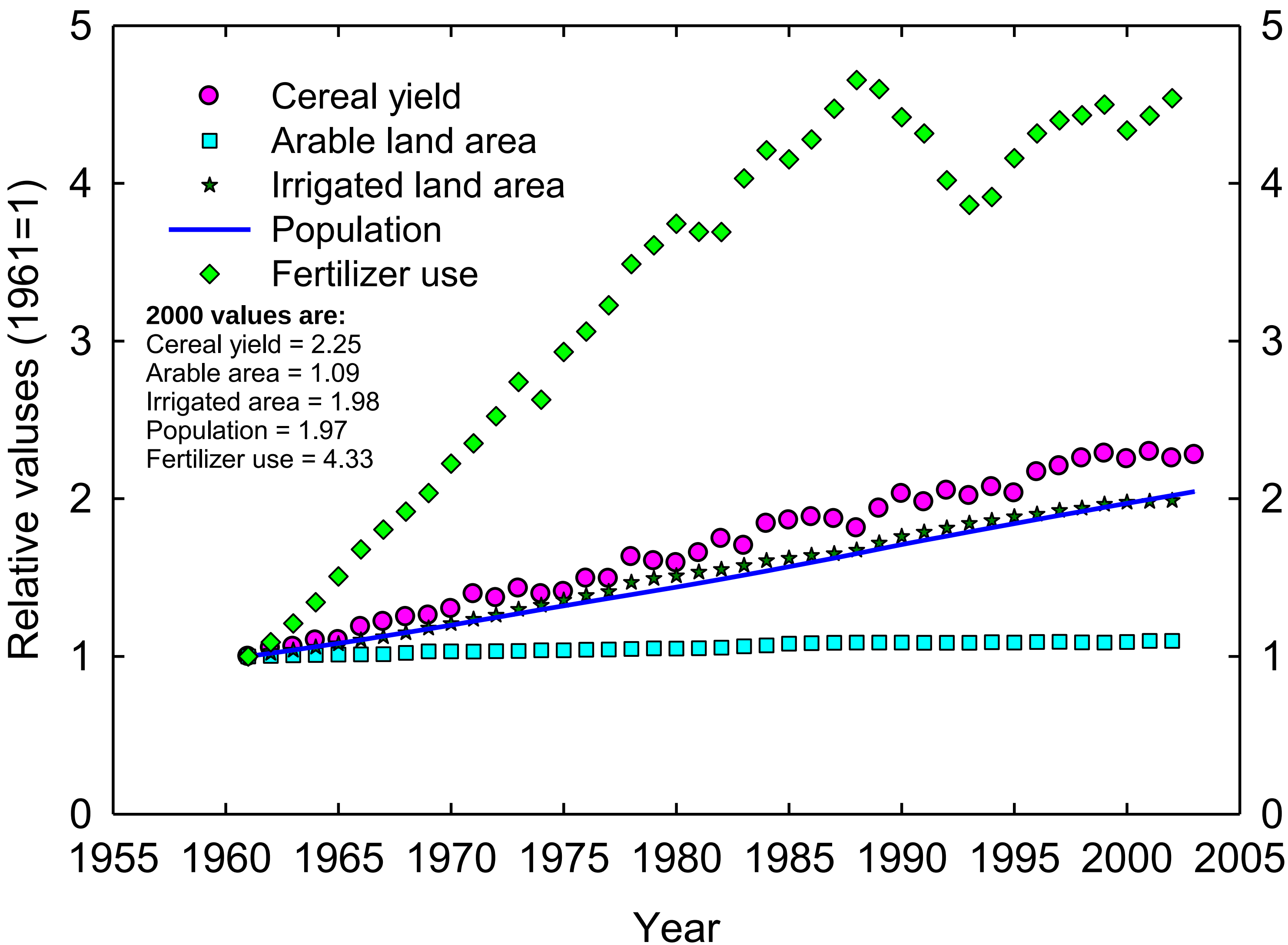
Year 2000

| | Cropland area | Irrigated area | Salinized area |
|---|---|---|---|
| | ----------------------------- | Mha | ------------------------------- |
| China | 124.0 | 54.4 (22%) | 7-8 (14%) |
| India | 161.8 | 54.8 (31%) | 10-30 (50%) |
| USA | 177.0 | 22.4 (13%) | 4.5 -6 (15%) |
| USSR | 204.1 | 19.9 (2%) | 2.5-4.5 (21%) |
| World | 1364.2 | 271.7 (21%) | 62-82 (37%) |

Percent change since 1985

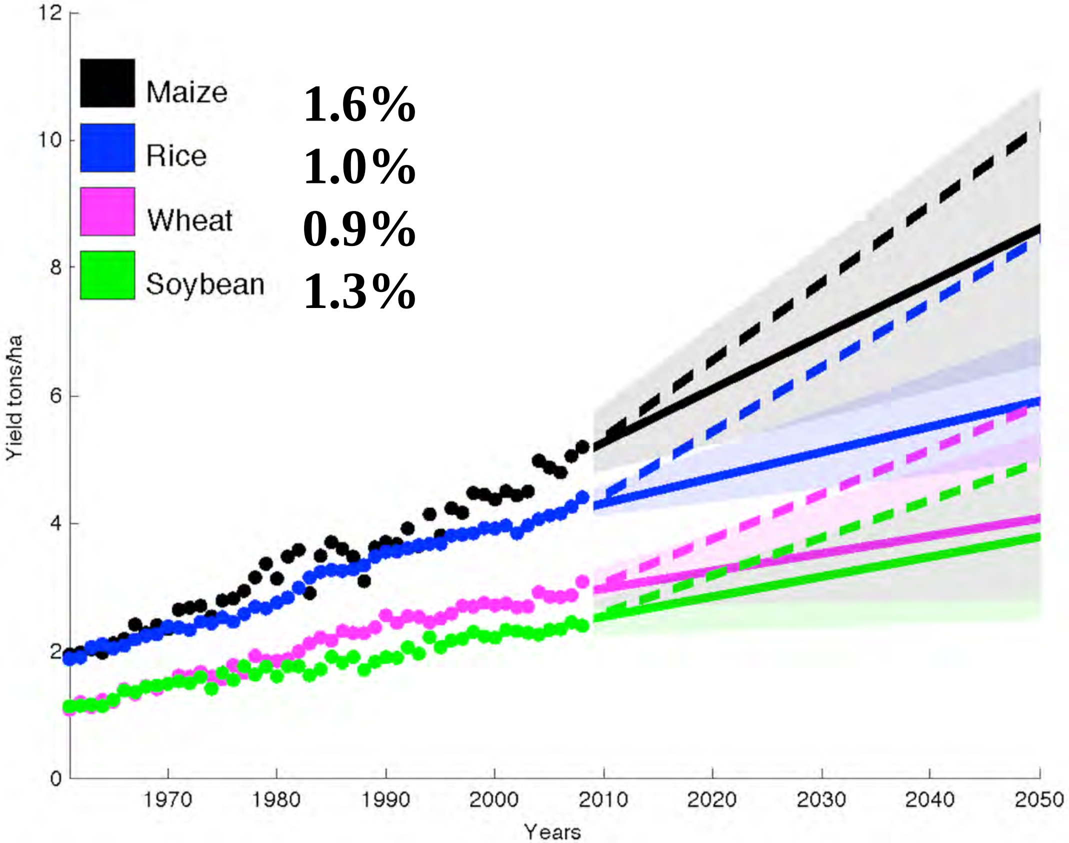
# Trends, Signs and Signatures from the Earth

## Population, cereal yield, arable and irrigated area, N use



# Trends, Signs and Signatures from the Earth

## Yield Trends of Major Crops – Past and Future




- Yield has to be doubled by 2050 to meet the demands of rising population with higher earning capacity, diet shifts, and increasing biofuels consumption.
- Based on past trends, projected rate of yield increase is about **1.2%** per year, but we need about **2.4%** per year to double the current yields for major cereal crops including rice.

Ray et al., 2013, PLOSOne

# Feeding 10 Billion Mouths

We must develop the capacity to feed over 10 billion people within in the next 35 to 85 years.

- The average world's current cereal yield is about 3.89 tons per ha for about 7.2 billion people (year 2014).
- We need about 5.24 tons per ha for 9.7 billion (2050; 35 % more than the current), and 5.94 tons per ha for 11 billion (2100; 53% more than the current).

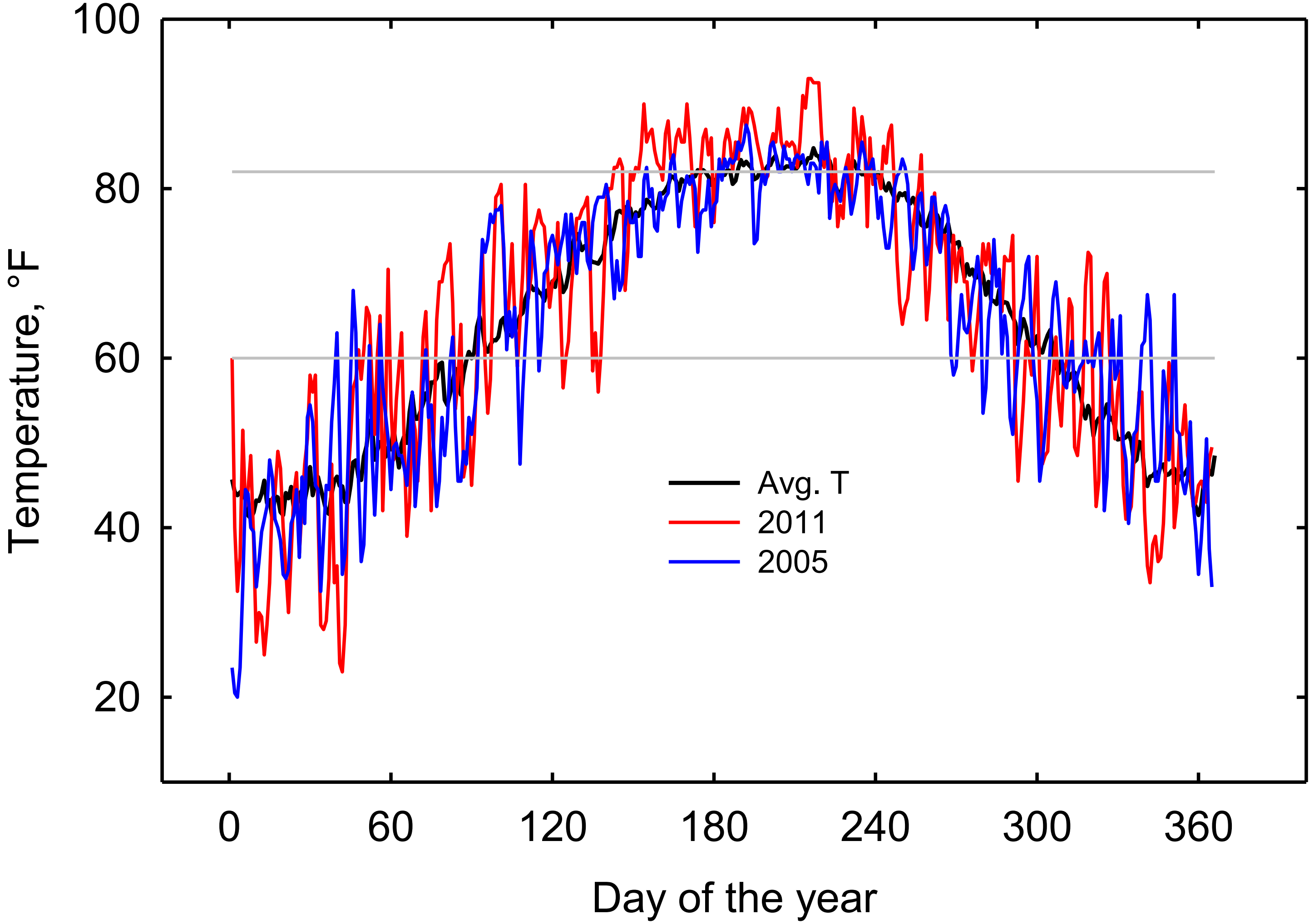
# Routes to Greater Food Production

- Increase in the area of land under cultivation.
- Increase in the number of crops per hectare per year (mostly practiced in tropics, requires access to irrigation, high input use, short season cultivars, and others such as labor, pest and disease control may be a problem).
- Displacement of lower yielding crops by higher yielding ones (done since the dawn of domestication).
- Efficiency of crop production in terms of:
  Per unit of land area (yield per ha)
  Per unit of time
  Per unit of inputs such as fertilizers, water and labor etc.


Here comes the greatest
challenge of our time,
The Global Climate Change

# Trends, Signs and Signatures from the Earth

## In a production environment, no two seasons are equal



# Environmental Stresses and Plant Growing Conditions

# Environmental and Cultural Factors Limiting Potential Yields

- Atmospheric carbon dioxide
- Solar radiation
- Temperature (extremes)
- Water (irrigation and rainfall)
- Wind
- Nutrients (N, P, K, and other nutrients)
- Others, Ultra-violet radiation, ozone etc.,
- Growth regulators (such as PIX)

# Area of Total World Land Surface Subject to Environmental Limitations of Various Types

| Limitation | Area of world soil subject to limitation (%) |
|---|---|
| Drought | 27.9 |
| Shallow soil | 24.2 |
| Mineral excess or deficiency | 22.5 |
| Flooding | 12.2 |
| Miscellaneous | 3.1 |
| None | 10.1 |
| Total | 100 |
| Temperature | 14.8 (over laps with other stresses) |

# Environmental Plant Physiology

## Chapter 1:

- Atmospheric carbon dioxide
- Solar radiation
- Temperature (Including extremes)
- Water (rainfall, flooding, and irrigation)
- Wind
- Nutrients
- Other factors such as ozone
- Plant growth regulators
- The facilities and tools

# Environmental Plant Physiology

## Chapter 2:

## **Photosynthesis and the environment**

- The Environmental productivity index (EPI) concept.
- The photosynthesis - Species variability.
- Photosynthesis and aging process.
- Respiration.

# Environmental Plant Physiology

## Chapter 3:

**Crop growth and development**

- Phenology
- Growth of various organs and whole plants.
- The concept of environmental productivity index in quantifying crop growth and development in response to the environment.

# Environmental Plant Physiology

## Chapter 4:

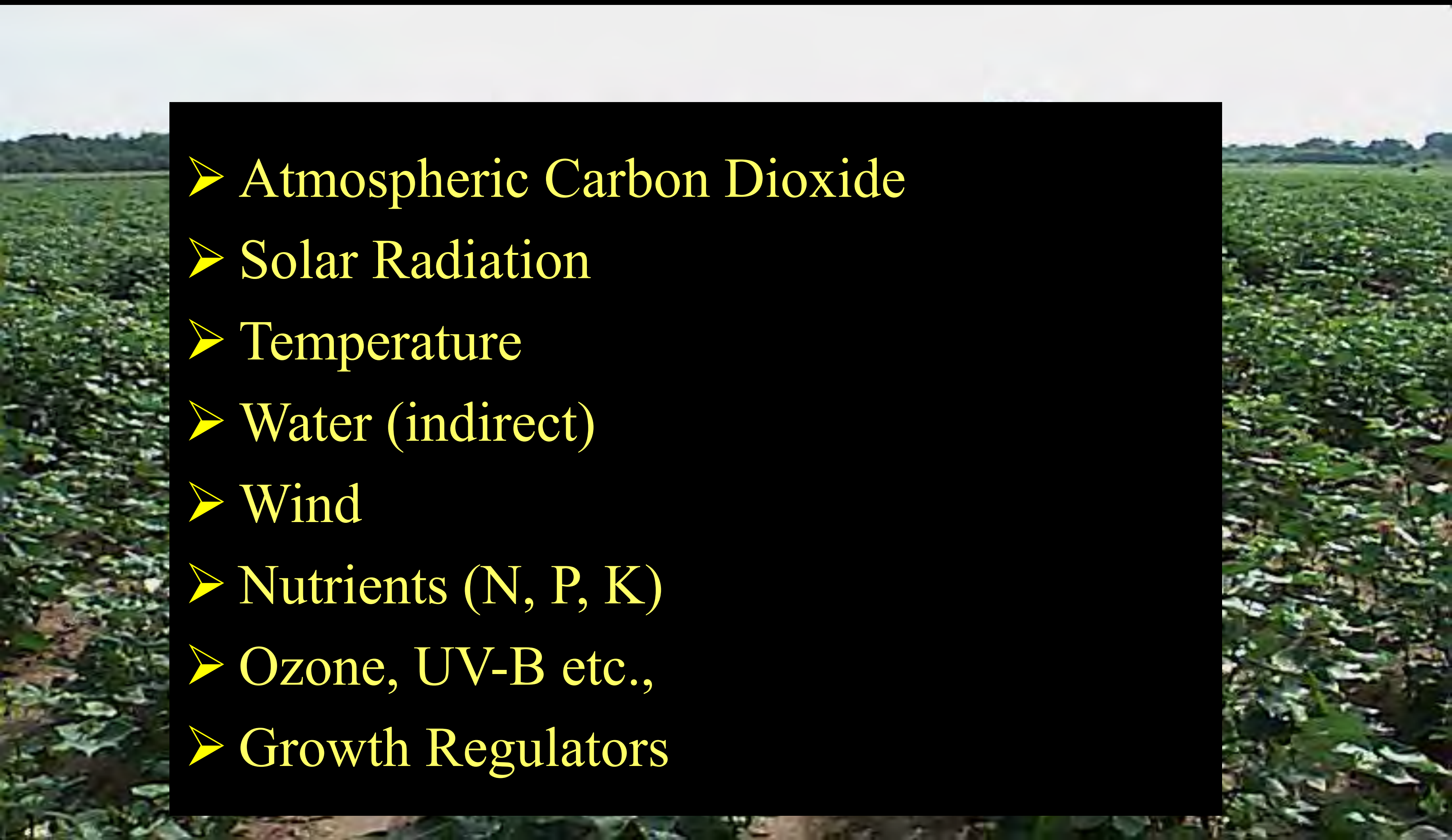
Scaling of processes from leaves to whole plant, canopies or ecosystems.

## Chapter 5:

Special topics include:

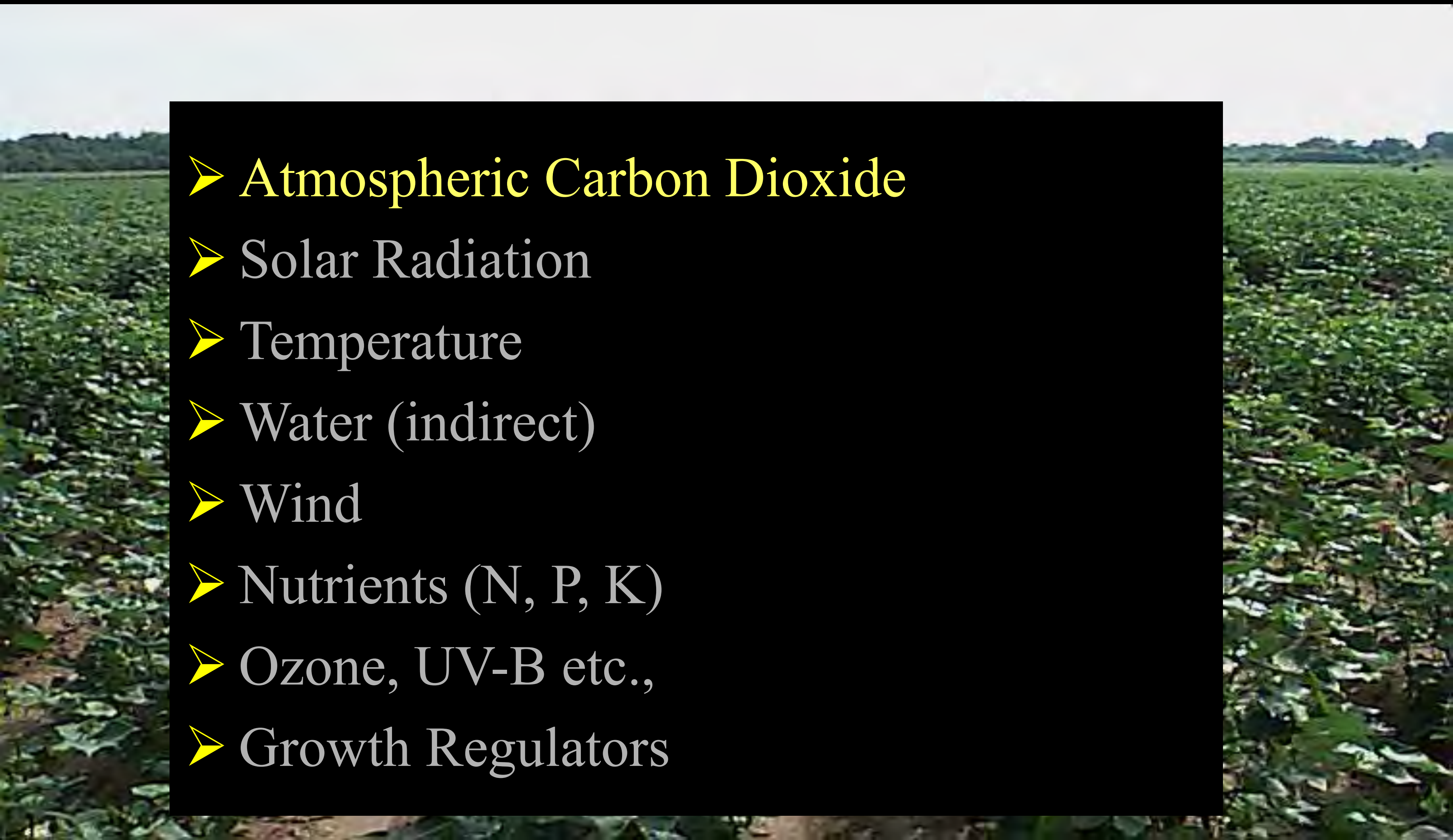
- Plant growth regulators – PIX.
- Remote sensing and environmental plant physiology.

# Environmental limiting crop growth, development and yield



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

# Environmental limiting crop growth, development and yield



- Atmospheric Carbon Dioxide
- Solar Radiation
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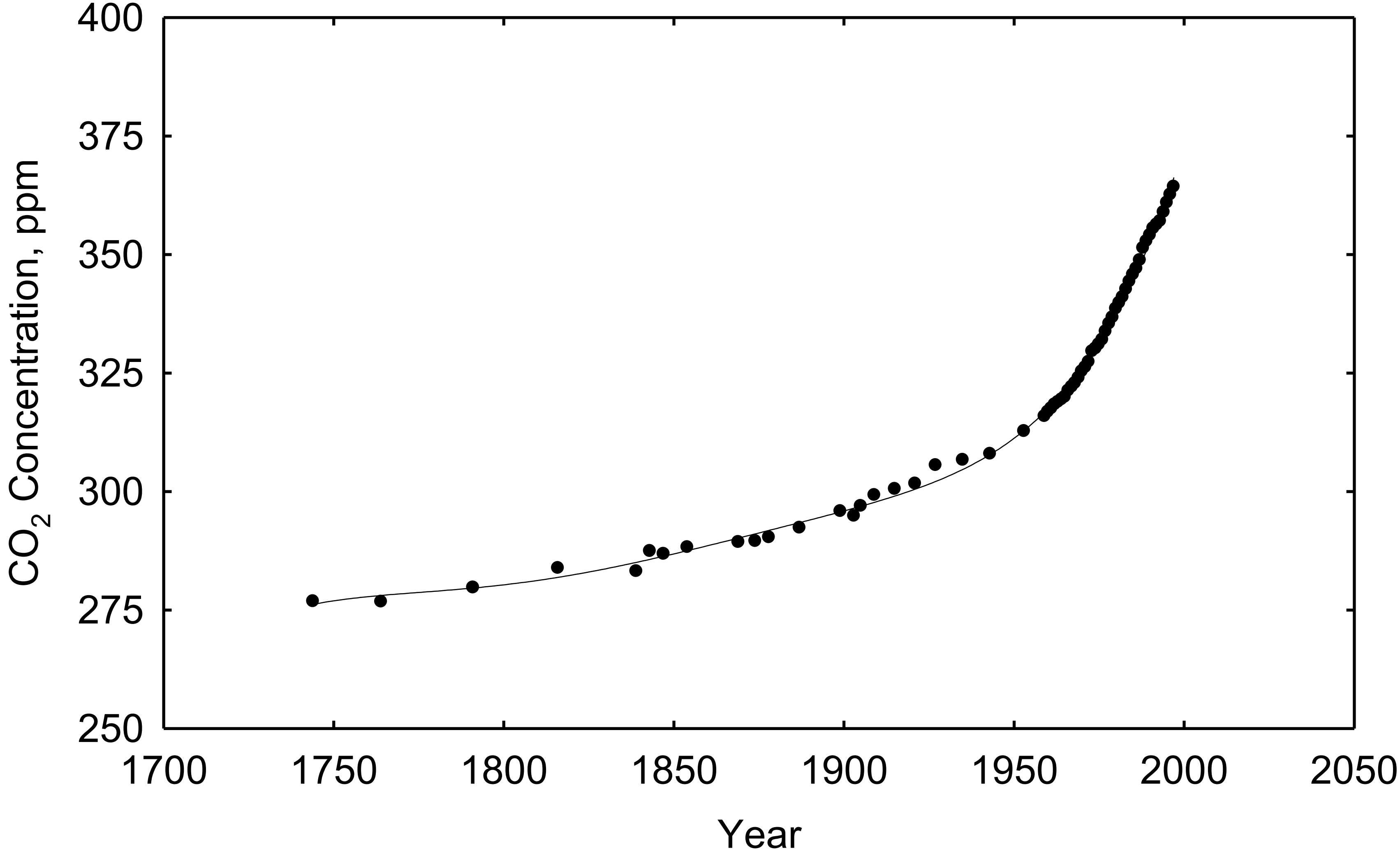
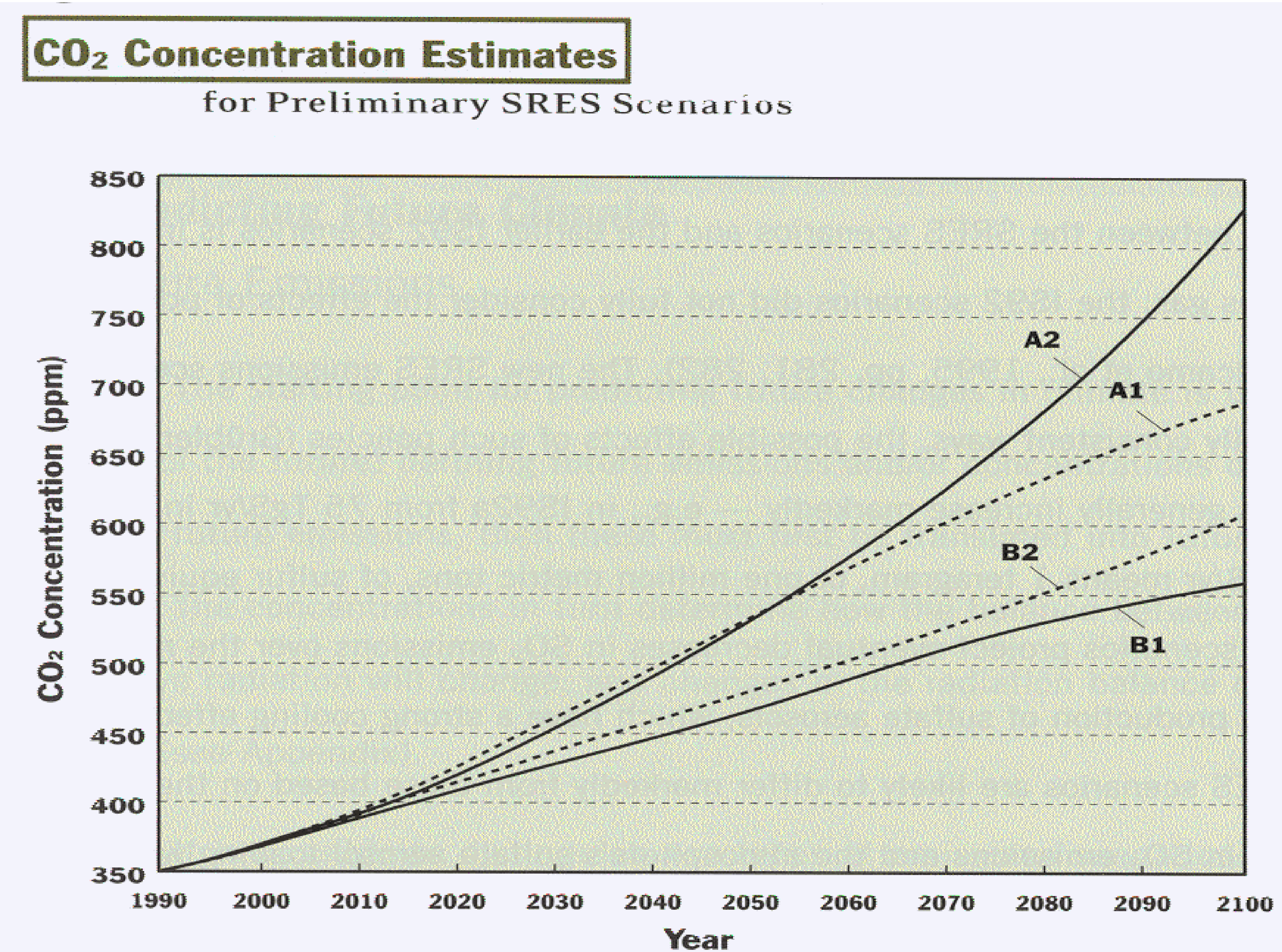
# Global Carbon Dioxide Concentrations

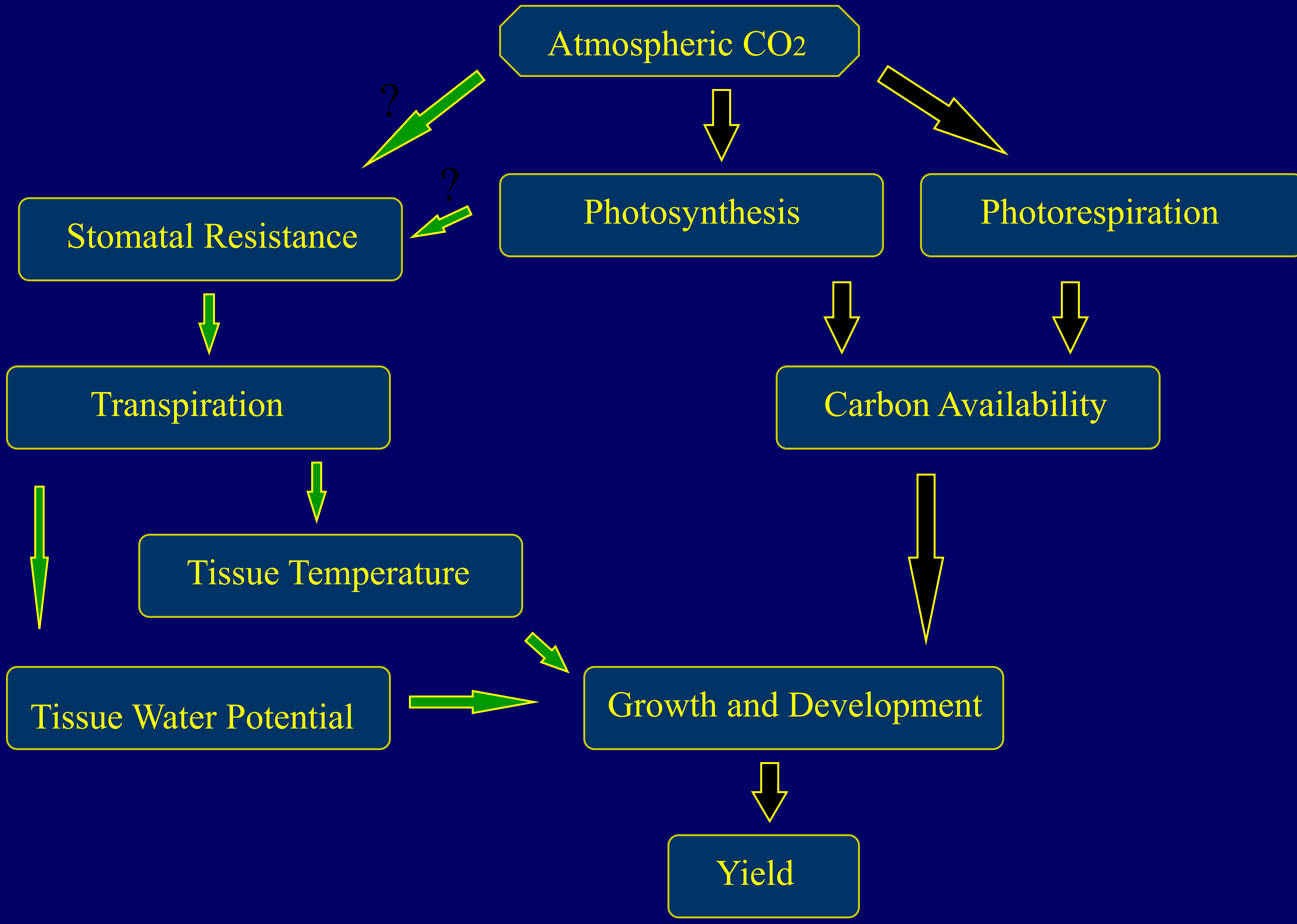
## Trends over the last two centuries





$CO_2$ Concentration Estimates
for Preliminary SRES Scenarios
$CO_2$ Concentration (ppm)
850
800
750
700
650
600
550
500
450
400
350
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
A2
A1
B2
B1

# A Hierarchy of Plant Responses to $CO_2$



# Environmental limiting crop growth, development and yield

- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

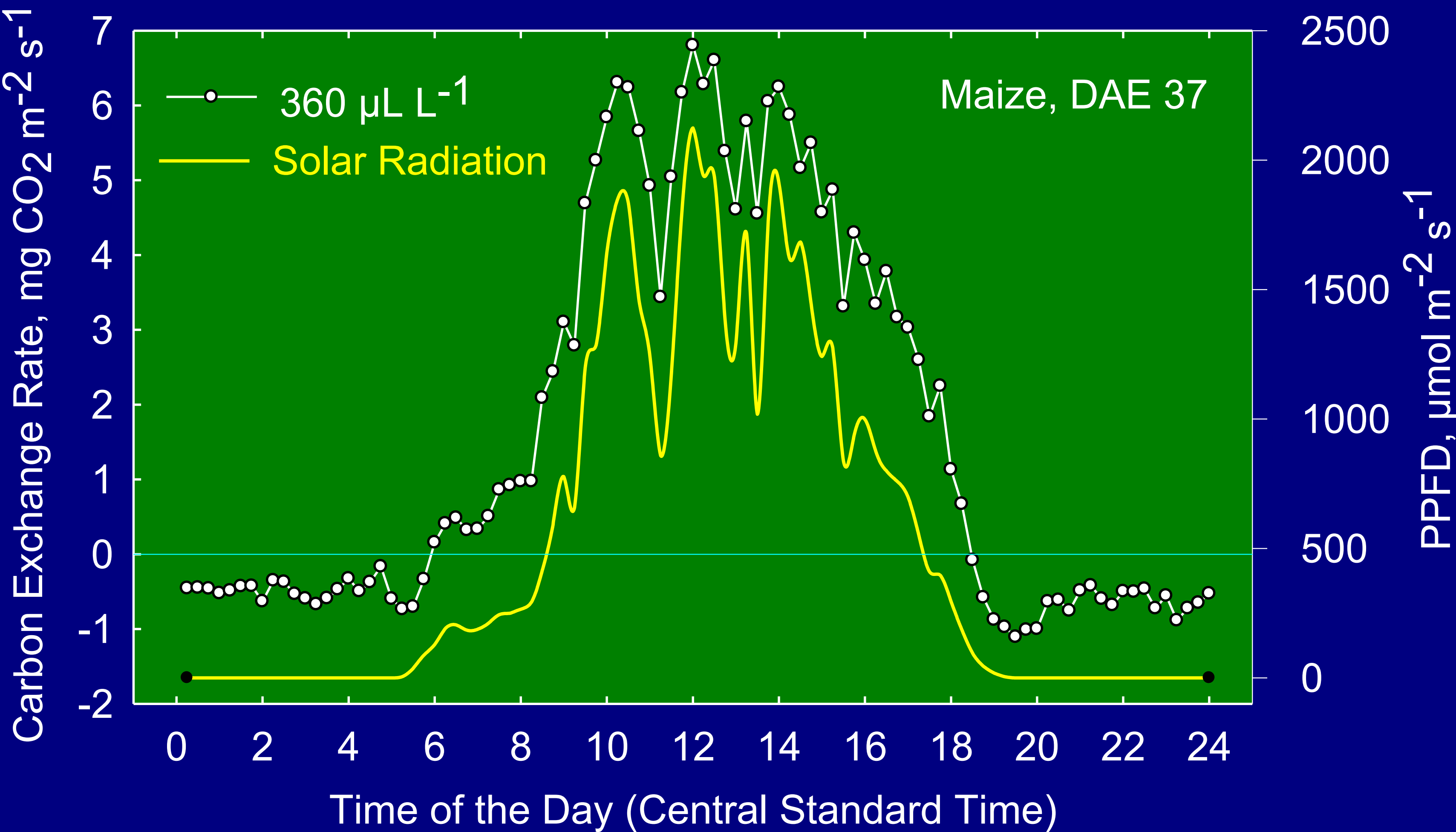
# Radiation and Plant Life

Table 1.6. Effect of radiation on plant life. (Ross 1981)

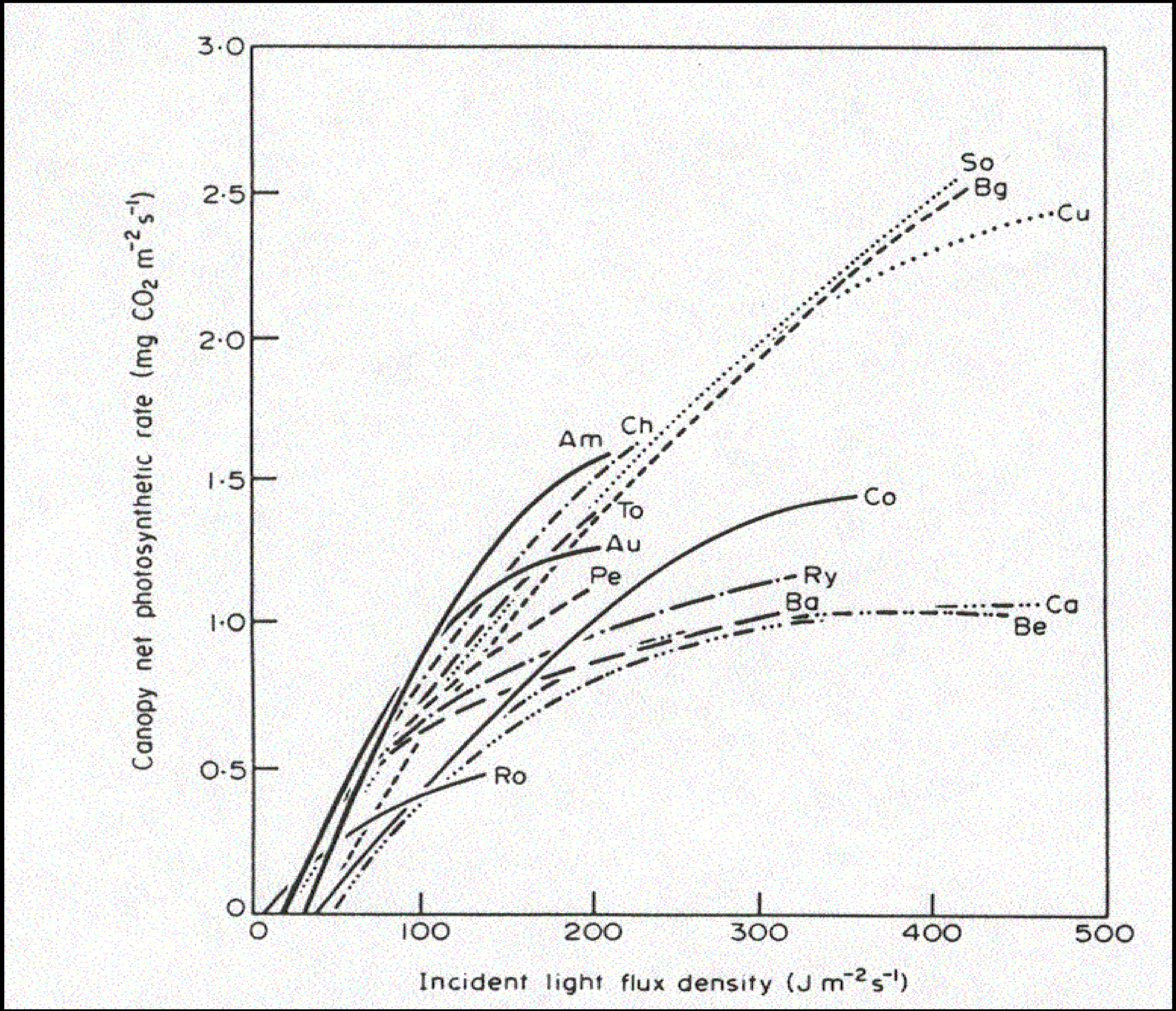
| Spectral region | Wavelength (nm) | Percent of solar radiant energy | Photo-synthetic | Effects of radiation | | |
|---|---|---|---|---|---|---|
| | | | | Photo-morpho-genetic | Photo-destruc-tive | Thermal |
| Ultraviolet | 290–380 | 0–4 | Insignificant | Slight | Significant | Insignificant |
| Photosynthetically active range (PhAR) | 380–710 | 21–46[a] | Significant | Significant | Slight | Significant |
| Infrared | 750–4000 | 50–79[a] | Insignificant | Significant | Insignificant | Significant |
| Longwave radiation | 4000–100000 | | Insignificant | Insignificant | Insignificant | Significant |

[a] Depending on position of sun and degree of cloud cover.

# Net Photosynthesis and Available Light Intensity



# Photosynthesis and Solar Radiation
## Species variability




Am – Amaranthus

Au – Aubergine

Ba – Barley

Be – Bean

Bg – Bermudagrass

Ca – Cabbage

Ch – Chrysanthimum

Co – Cotton

Cu – Cucumber

Pe – Pepper

Ro – Rose

Ry – Ryegrass

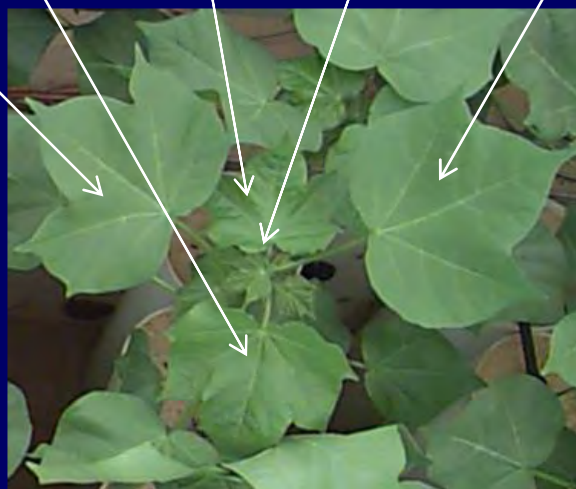
So – Sobean

To - Tomato

# Leaf and canopy development and aging process

## Leaf

12-day
5-day
2-day
Emerging leaf
8-day



About to abscise

## Canopies

Emergence

Squaring

Flowering

Mature crop

# Solar Radiation and Dry Matter Production

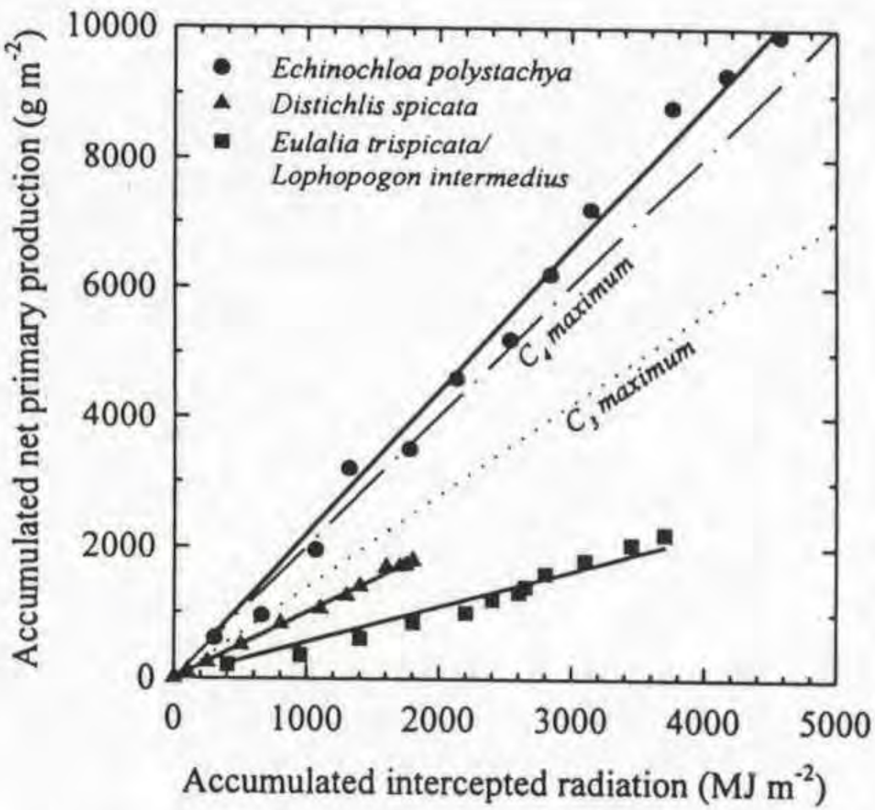


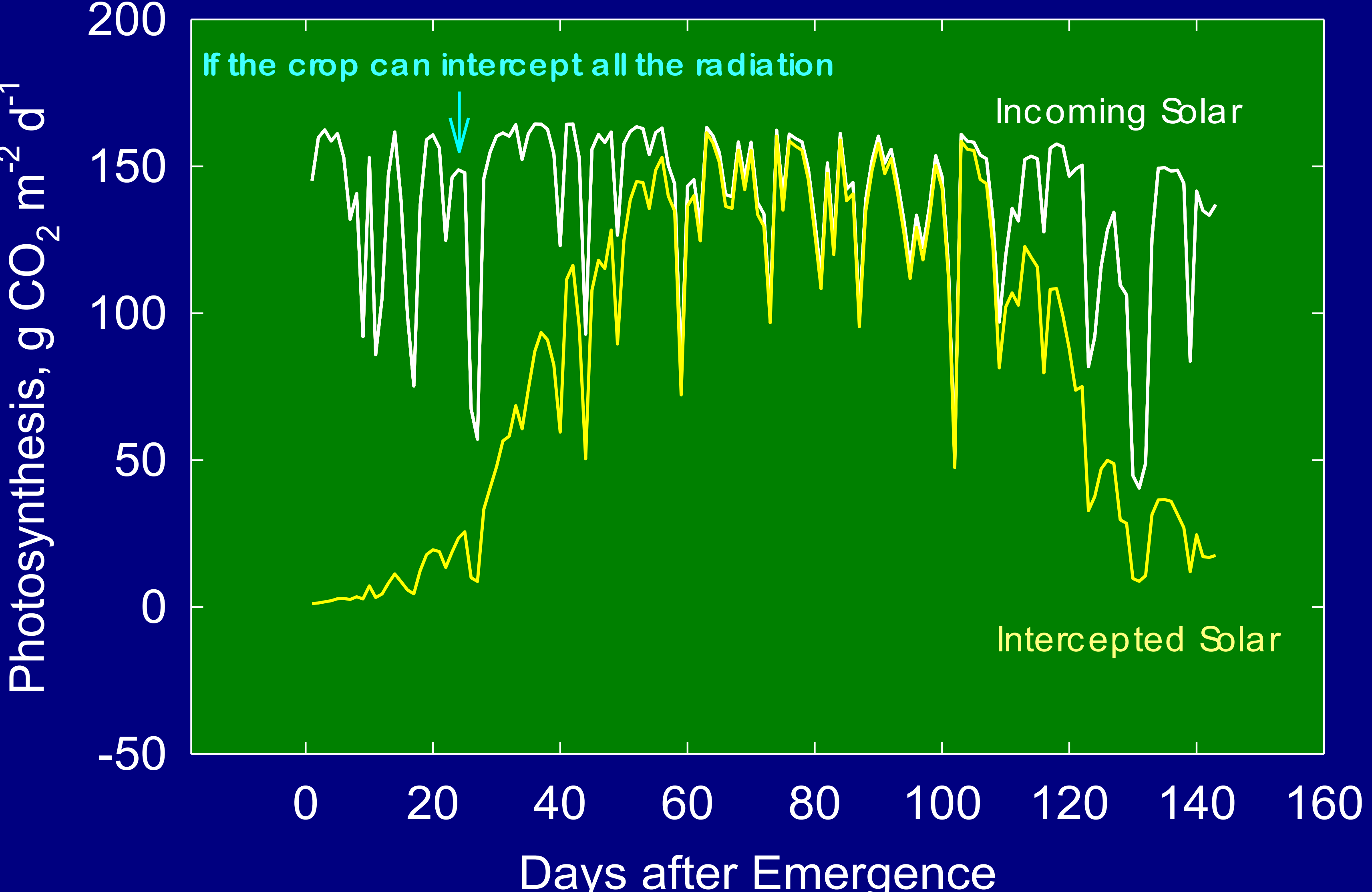

**Figure 1** Accumulated monthly mean values of net primary production plotted against the accumulated quantity of total solar radiation (all wavelengths) intercepted by the same communities. Solid lines are the best-fitting straight lines to the illustrated data points. Data are for: (●) monotypic stands of *Echinochloa polystachya* on the Amazon floodplain near Manaus, Brazil (Piedade *et al.*, 1991); (▲) monotypic stands of *Distichlis spicata* on saline grassland close to Mexico City (Jones *et al.*, 1992); and (■) mixed $C_4$ grass stands codominated by *Eulalia trispicata* and *Lophopogon intermedius* in moist savanna near Hat Yai, Thailand (Kamnalrut and Evenson, 1992). The broken lines indicate the maxima suggested for the two photosynthetic types (after Monteith, 1978). Data redrawn from Piedade *et al.* (1991) and Jones *et al.* (1992).

# Effects of Multiple Environmental Factors on Crop Growth and Developmental Aspects

- Introduced Environmental Productivity Index (EPI) concept.
- Photosynthesis
- Crop Phenology or Development
- Crop Growth
- Reproductive Biology

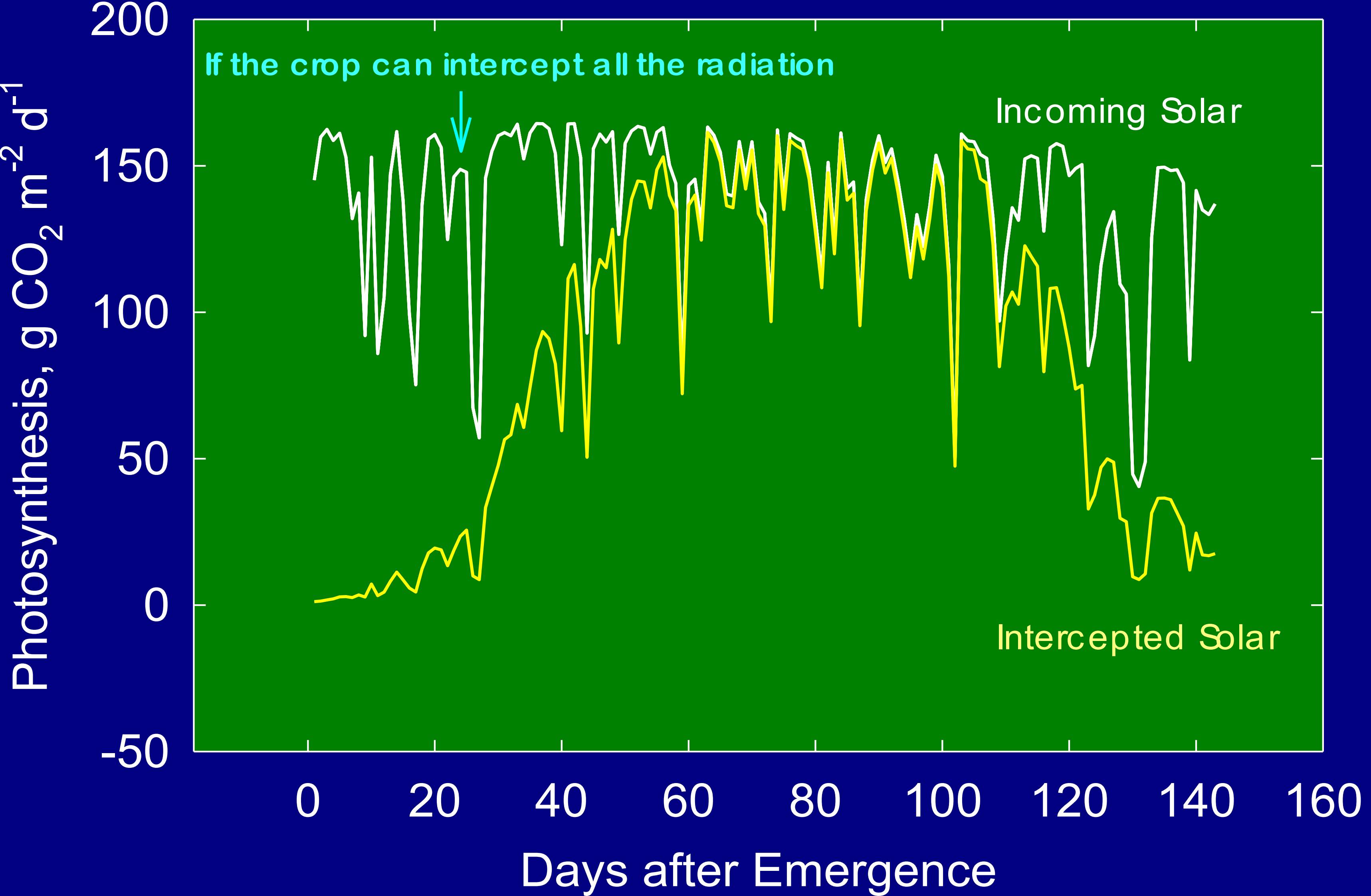
# Canopy Photosynthesis - Growing Season

## Accounting for environmental factors using EPI concept



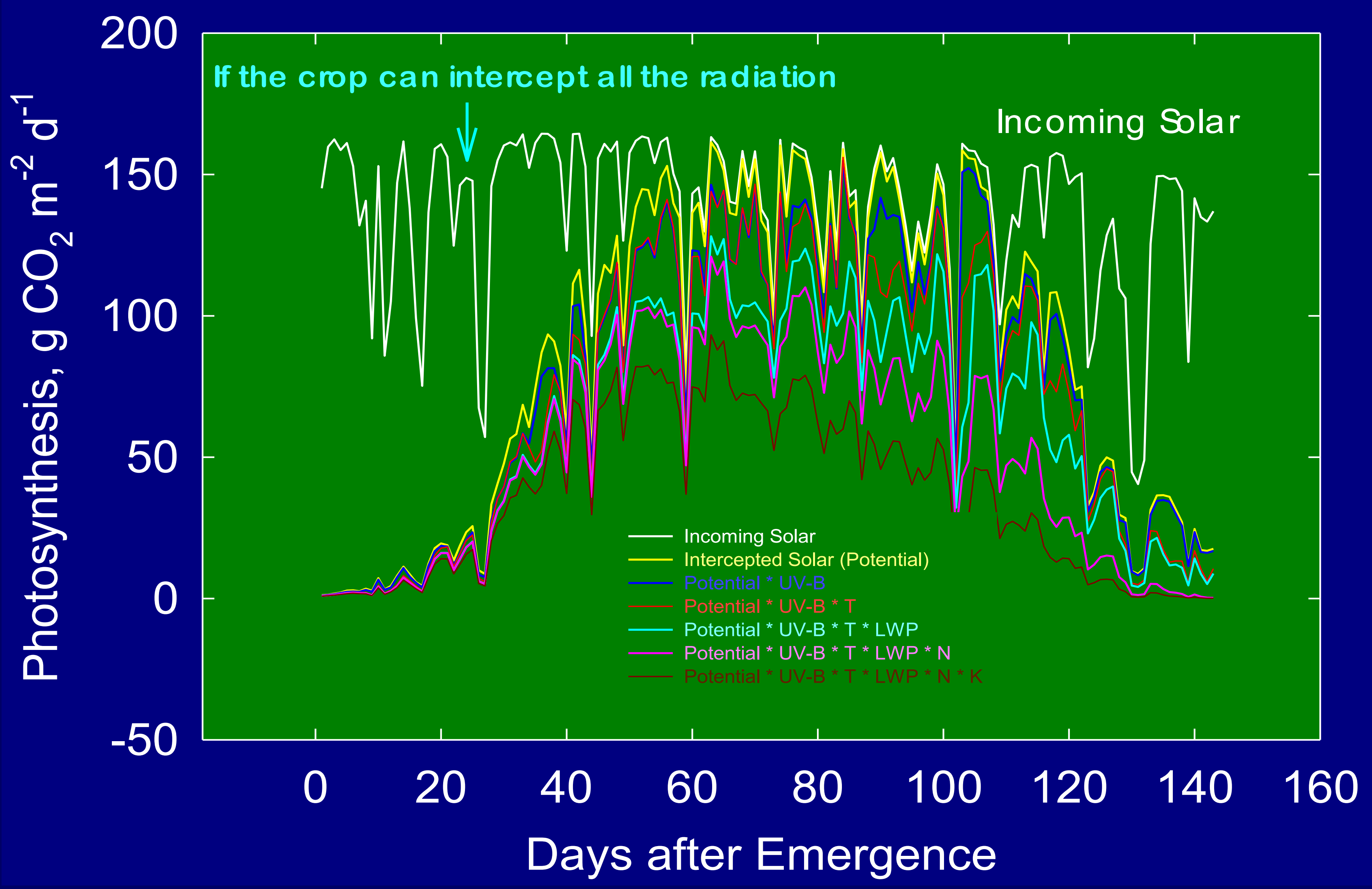
# Canopy Photosynthesis - Growing Season

## Accounting for environmental factors using EPI concept



# Canopy Photosynthesis - Growing Season

## Accounting for environmental factors using EPI concept



# Radiation Totals for the 1992 Growing season Mississippi State – North Farm

| Variable | Amount, MJ |
|---|---|
| Total Incoming Radiation | 2842 |
| Intercepted Radiation | 1551 |
| Percent Intercepted | 55 |

# Photosynthesis – EPI Concept
# Accounting for Individual factors

| Variable | Amount, g $CO2\ m^{-2}\ season^{-1}$ |
|---|---|
| Incoming R | 19644 |
| Intercepted R | 11441 (100%) |
| Int. R * UV-B | 10448 (9%) |
| Int. R.* T | 10139 (11%) |
| Int. R.* W | 9783 (14%) |
| Int. R.* N | 8986 (21%) |
| Int. R * K | 10841 (5%) |

# Photosynthesis – EPI Concept
# Accounting for Multiple Factors

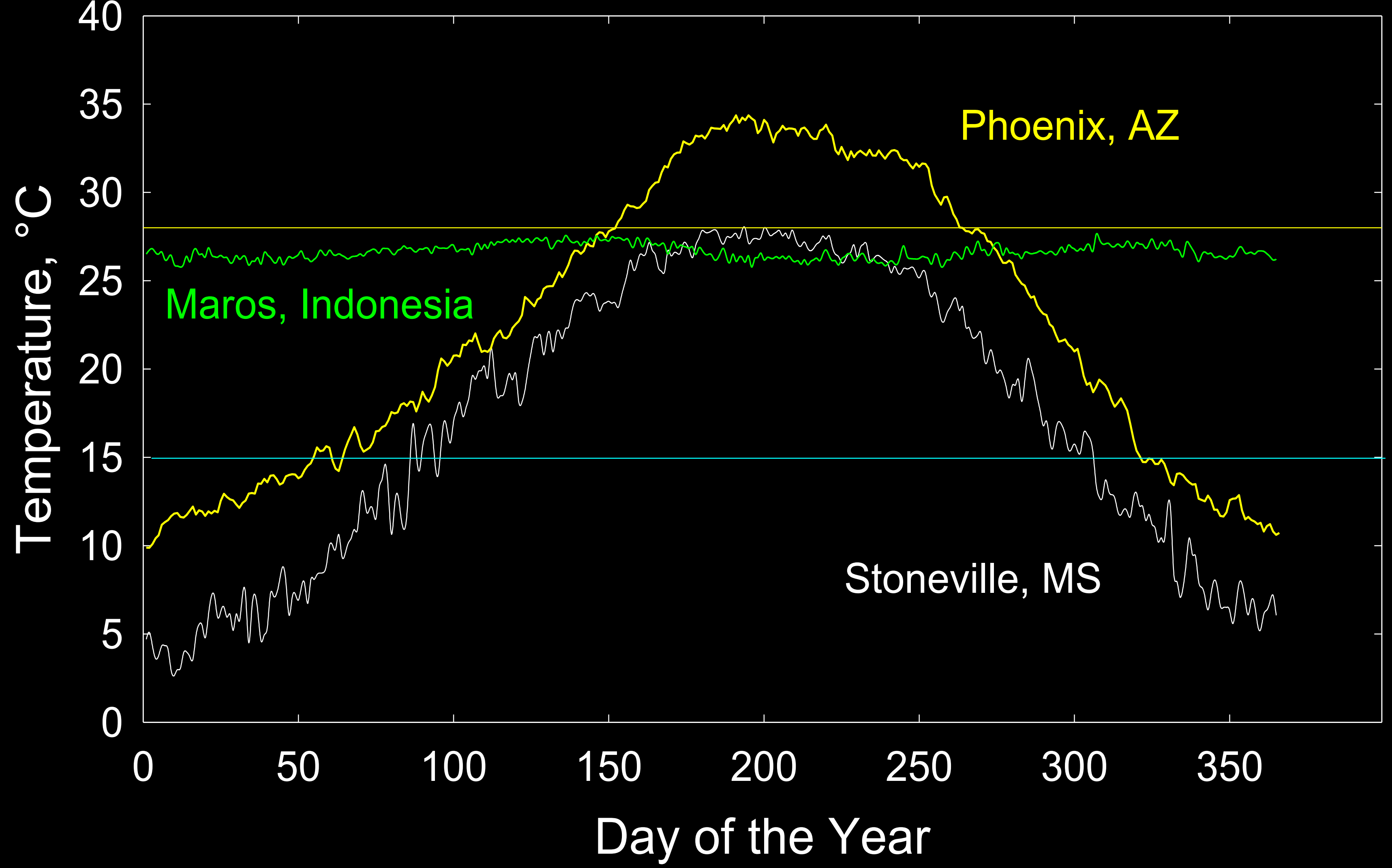
| Variable | Amount, g CO2 $m^{-2}$ $season^{-1}$ |
|---|---|
| Incoming R | 19644 |
| Intercepted R | 11441 (100%) |
| Int. R* UV-B | 10230 (9%) |
| Int. R* UV-B*T | 9153 (20%) |
| Int. R* UV-B*T*W | 7551 (34%) |
| Int. R*UV-B*T*W*N | 6292 (55%) |
| Int. R*UV-B*T*W* K | 4576 (60%) |

Actual amount

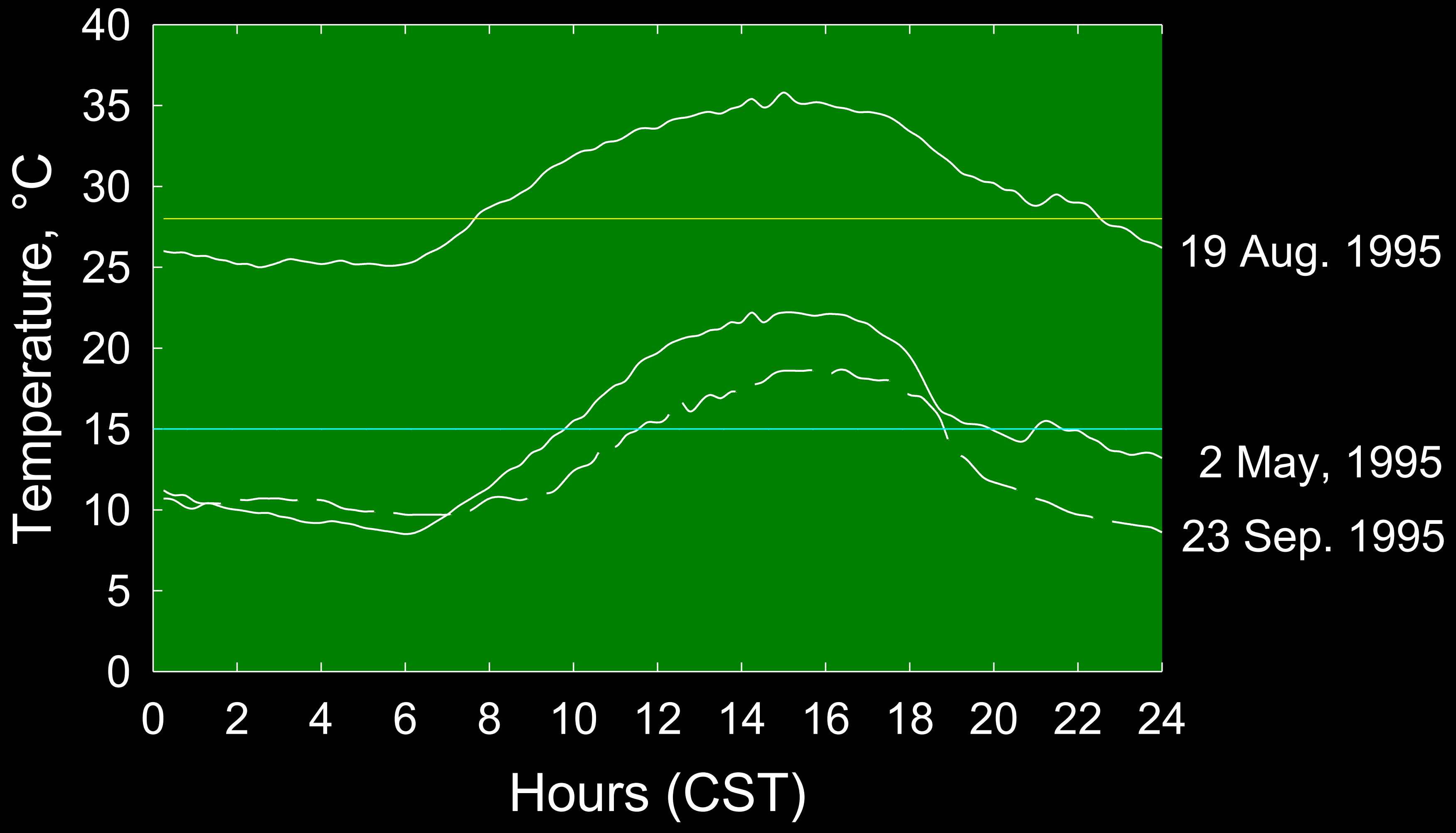
# Environmental limiting crop growth, development and yield

- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

# Long-Term Average Temperatures



# Temperature Conditions - Diurnal Trends
## Mississippi State, MS - 1995



Central **Temperature Estimates** Plus Extremes for the Preliminary SRES Scenarios

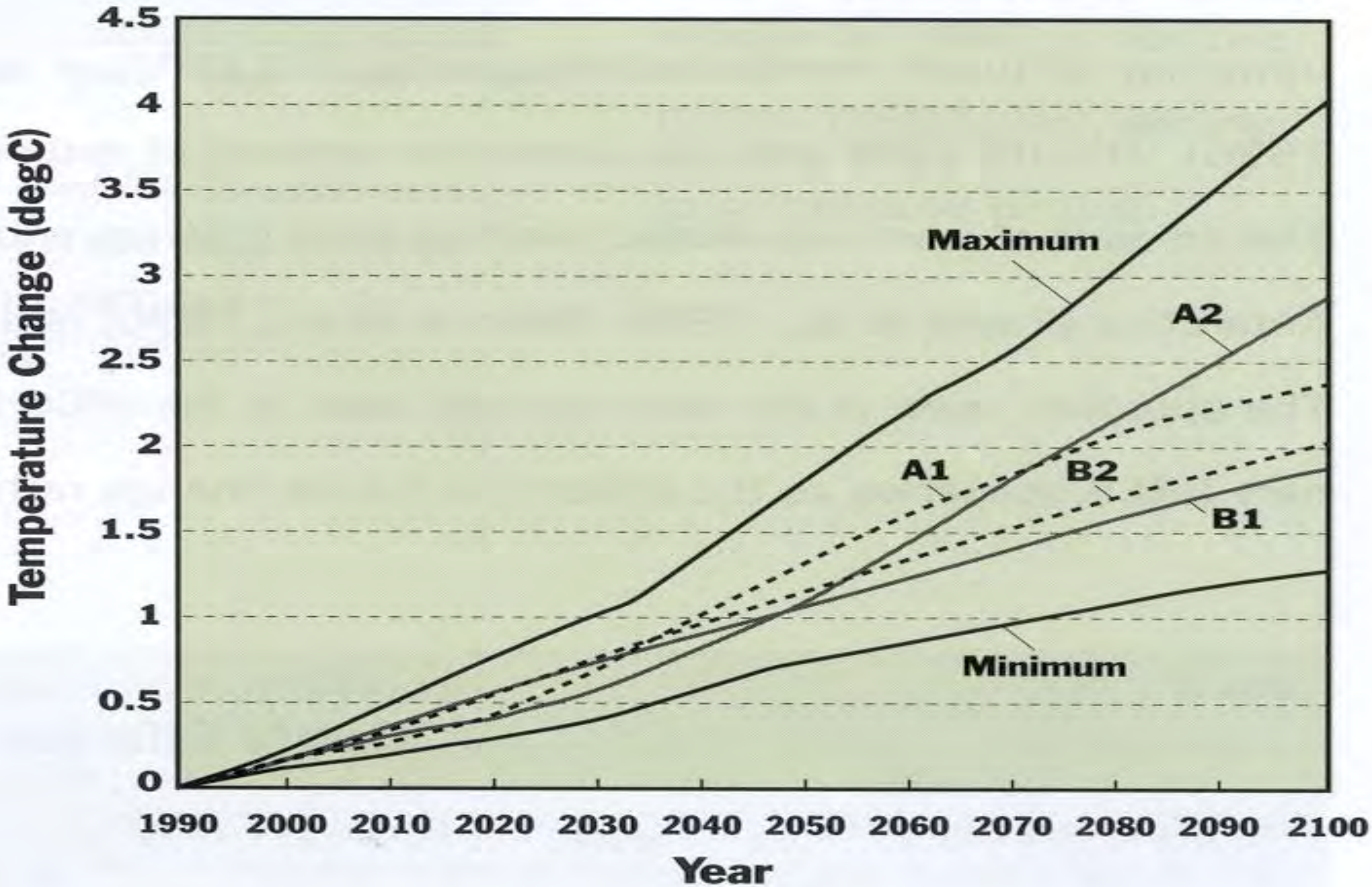
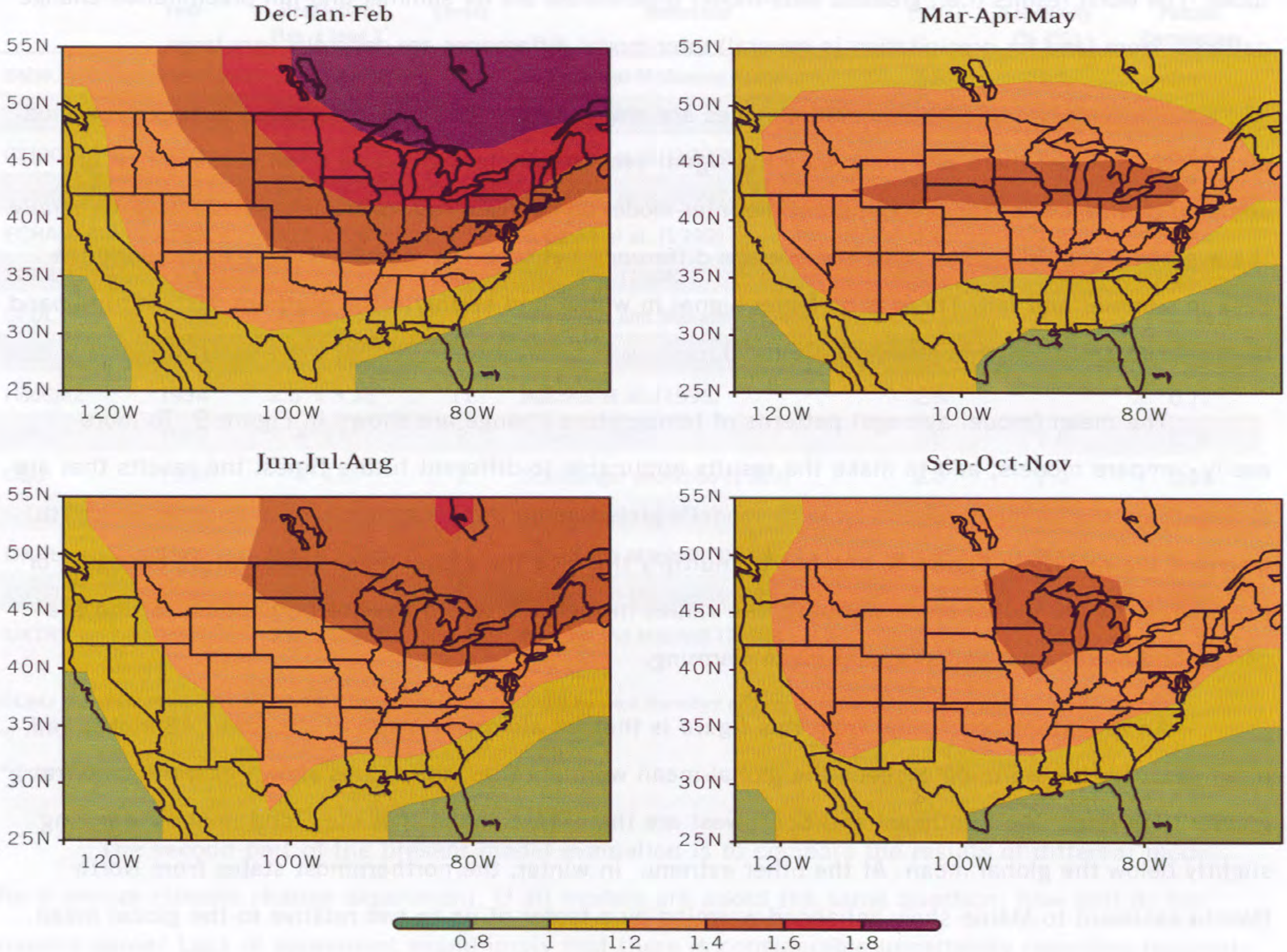


*Figure 9*

**Relative Temperature Changes** Mean of 15 Models



# Environment Factors

Temperature:

- Strongly Affects:
  - -- *Phenology*
  - -- *Vegetative growth, LAI, LAD*
  - -- *Fruit Growth and Retention*
  - -- *Respiration*
  - -- *Water-loss and Water-Use*
- Moderately Affects:
  - -- *Photosynthesis on a canopy basis*

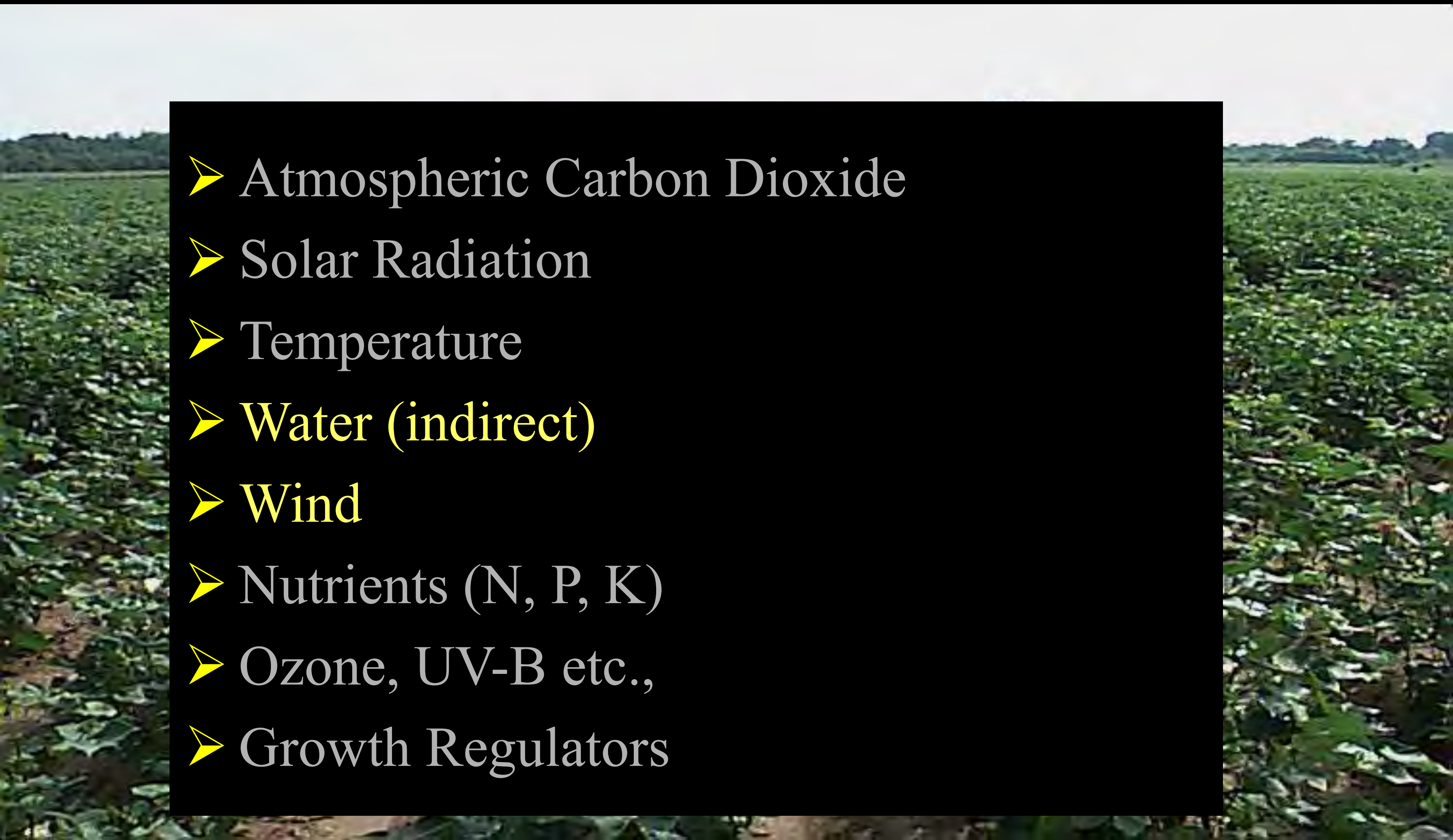
# High-temperature Injury

Heat-blasted Cotton Squares
California's San Joaquin Valley

**Figure 7.** Heat-blasted squares in California's San Joaquin Valley. (Photo: R. Vargas)

Heat-blasted Cotton Flowers and Squares – Arizona

# Environmental limiting crop growth, development and yield



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

# Water

Water plays essential roles in plants as a:

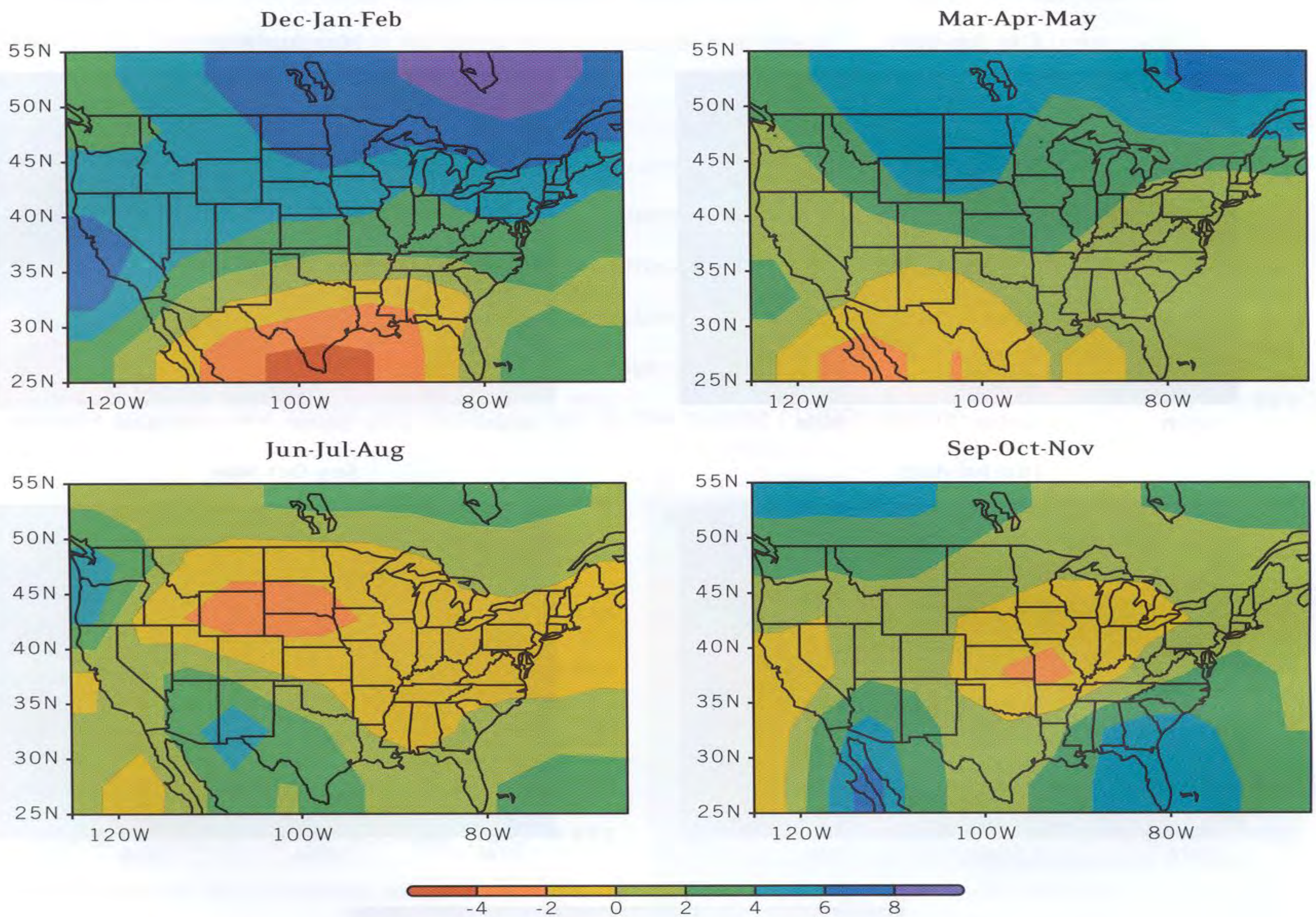
- Constituent
- Solvent
- Reactant in various chemical processes
- Maintenance of turgidity

The physiological importance of water is reflected in its ecological importance.

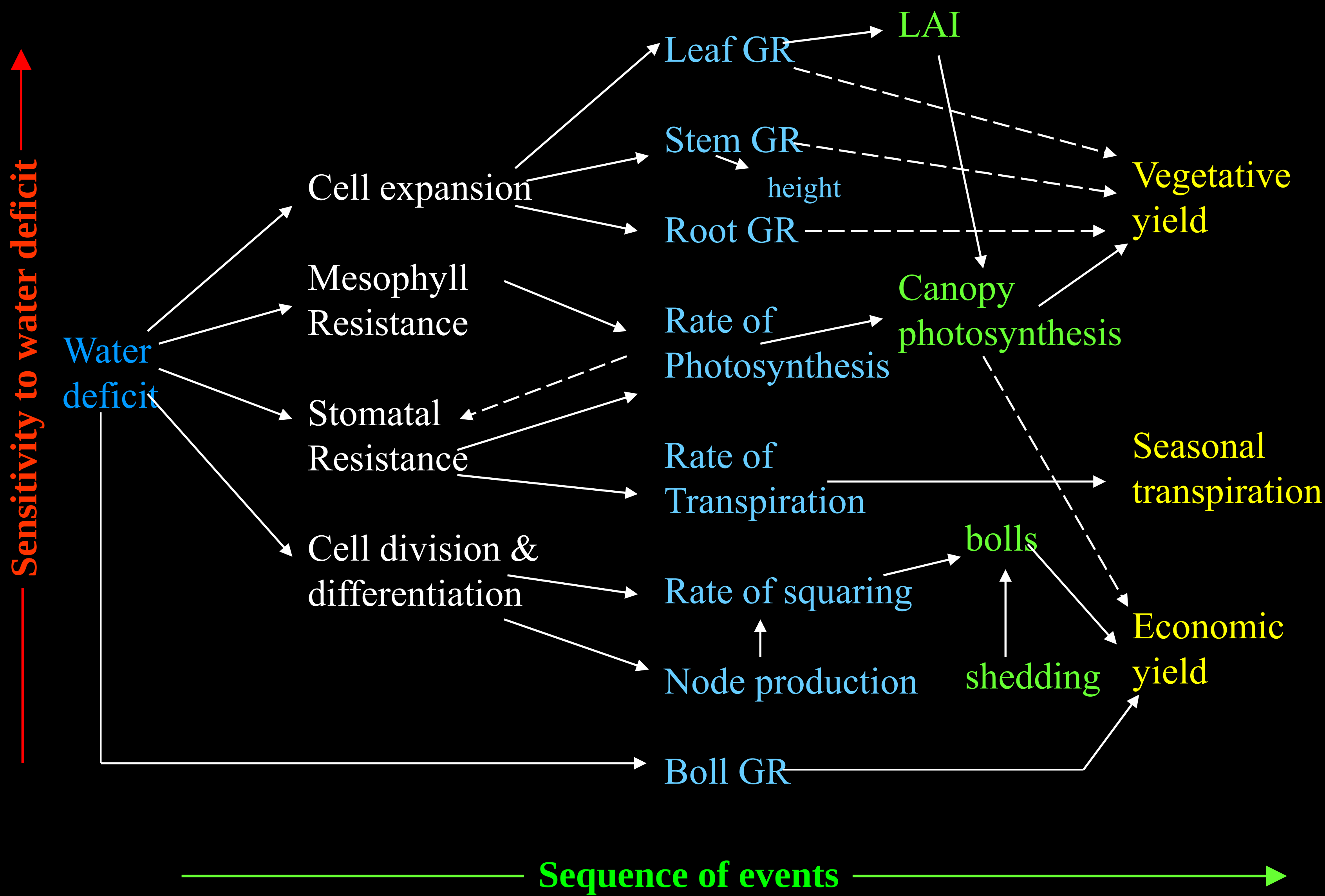
The distribution plants over the earth's surface is controlled by the availability of the water (amount and seasonal distribution of precipitation) where ever temperature permits growth.

*Figure 10*

**Relative Precipitation Changes (%/°C)** Mean of 15 Models



# Role of water in cotton



# Environment Factors

## Water Deficits:

- Strongly affects:
  - -- *Vegetative growth, LAI, LAD*
  - -- *Fruit Growth and Retention*
  - -- *Water-loss and Water-Use*
  - -- *Photosynthesis*

- Moderately affects certain phenological events:
  - -- *Phenology (leaf development)*

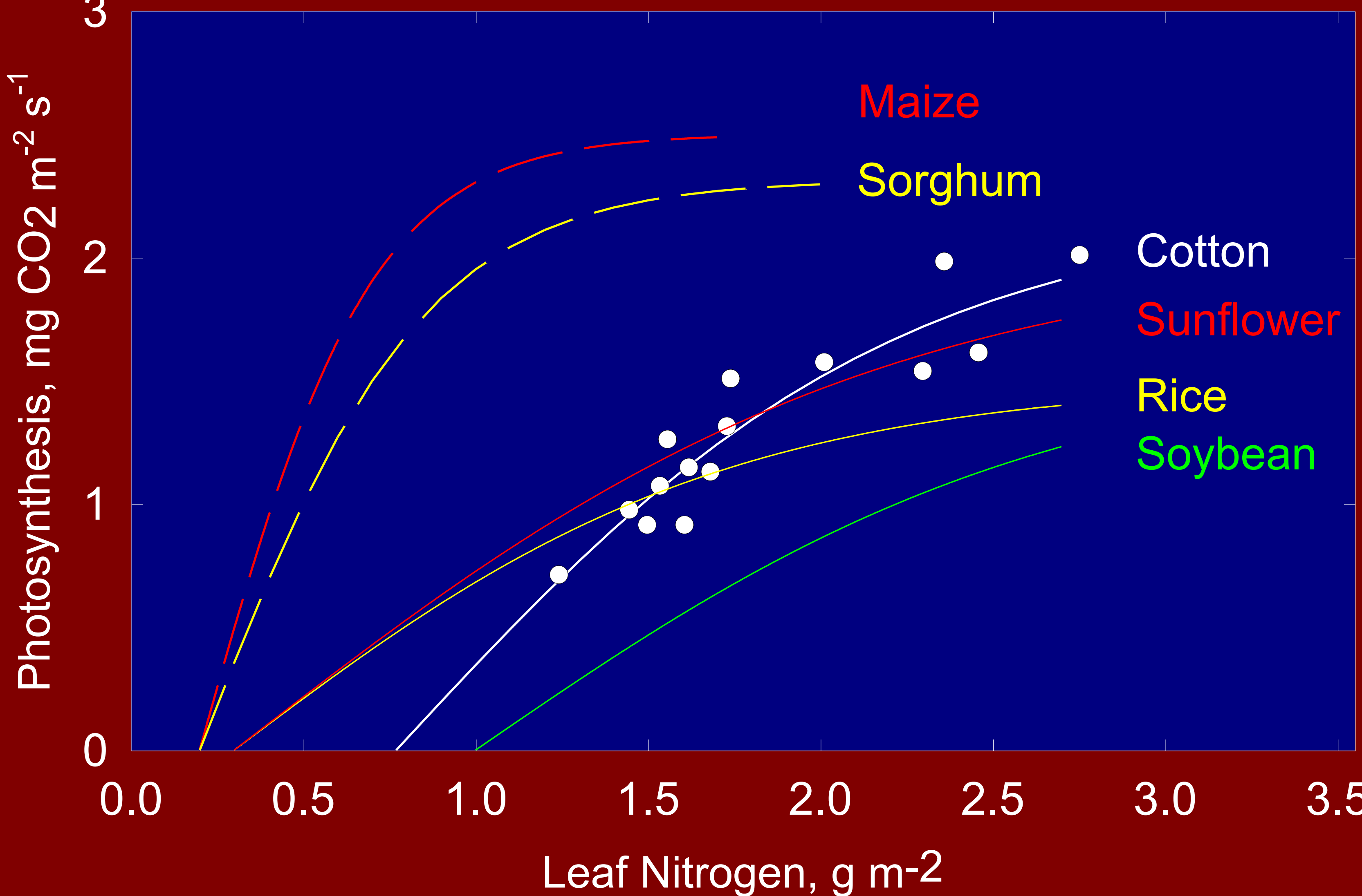
# Environment – Wind and Hail

# Environmental limiting crop growth, development and yield

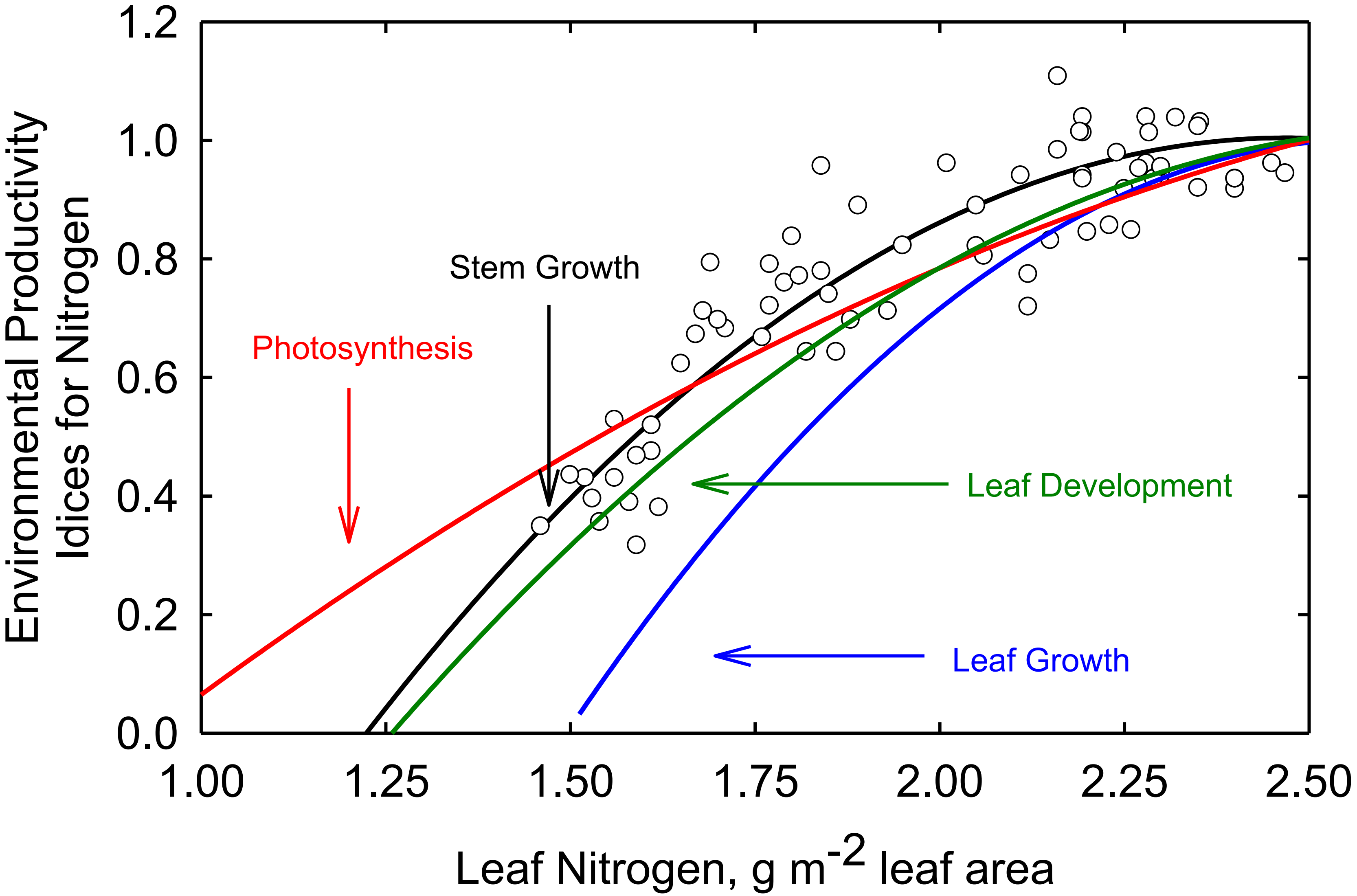
- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

# Photosynthesis - Variability Among Species

## Response to Leaf Nitrogen



# Environment - Nitrogen



# Environment - Nitrogen

| Parameter | Percent Reduction from the Optimum (2.5 g N/m$^{-2}$ or 4.5%) | | | |
|---|---|---|---|---|
| Leaf N, g m$^{-2}$ | Photosynthesis | Stem growth | Leaf growth | Leaf Development |
| 2.5 | 100 | 100 | 100 | 100 |
| 2.0 | 12 | 14 | 18 | 12 |
| 1.5 | 53 | 60 | >99 | 68 |
| 1.2 | 76 | -- | -- | -- |

# Environment - Nitrogen

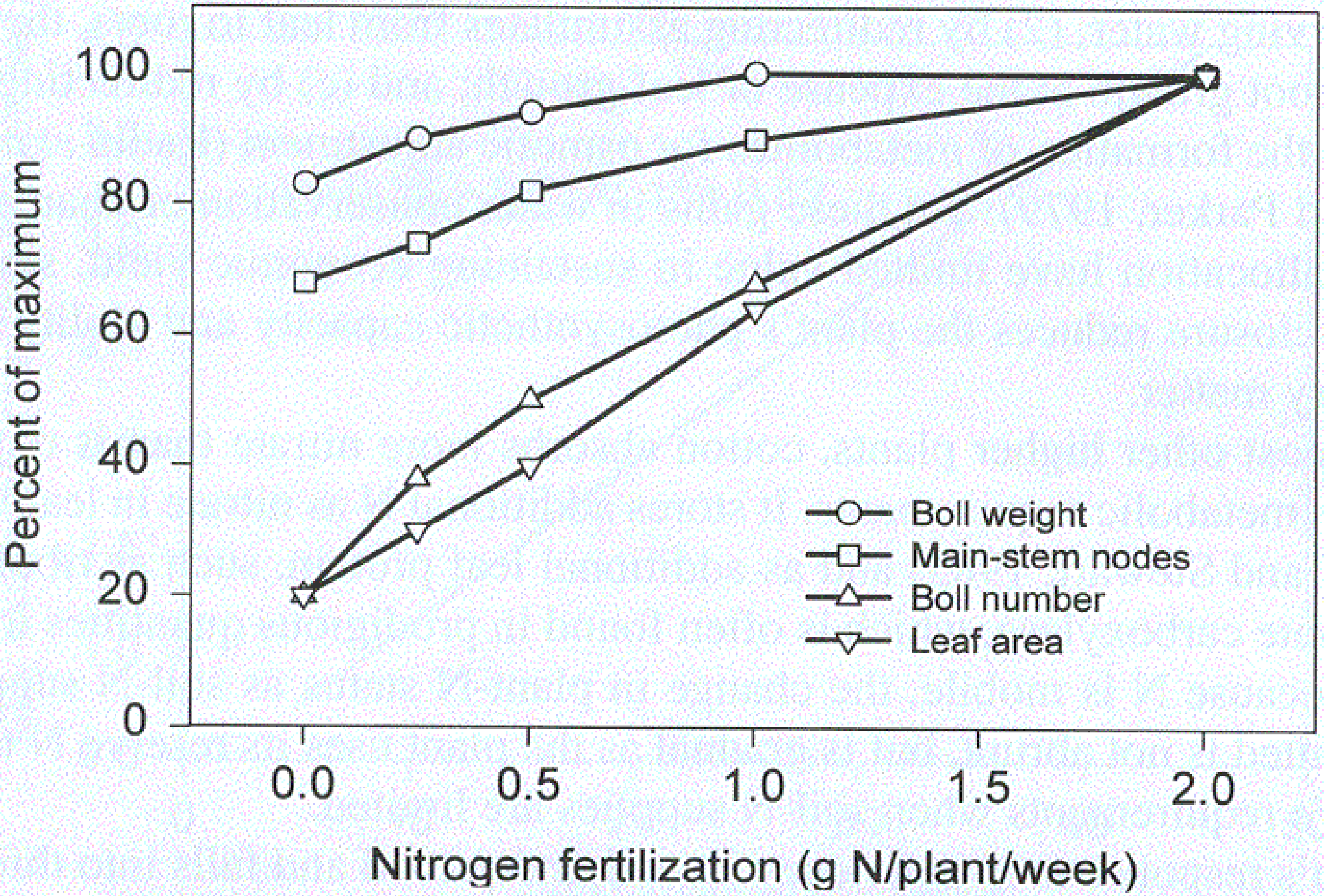



**Figure 2** The effect of N on number of main-stem nodes, boll number per plant, leaf area, and boll weight (Jackson and Gerik, 1990).

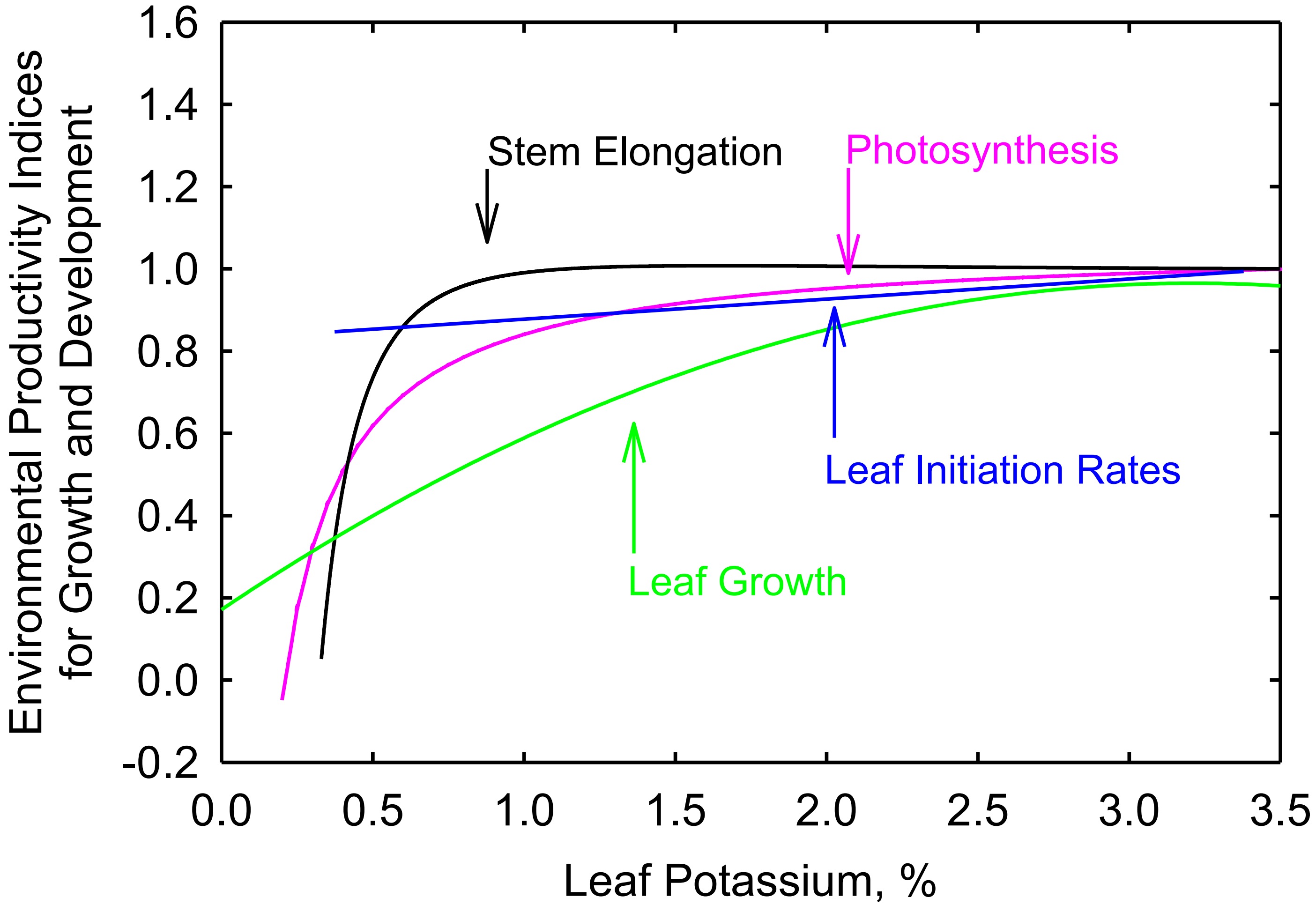
# Environment Factors

Fertilizers Deficits - Potassium:

- Strongly Affects:
  - -- *Leaf growth, LAI, LAD*
  - -- *Fruit Retention*
- Moderately Affects:
  - -- *Photosynthesis*
  - -- Stem growth

# Environment - Nutrients

## Potassium - Cotton Growth and Development
## Environmental Productivity Indices



# Environment Factors

Ultraviolet-B Radiation:

- Strongly Affects:
  - -- *Photosynthesis*
  - -- *Stem growth*
- Moderately Affects:
  - -- *Leaf growth*
  - -- *Leaf aging*
- No Effects:
  - -- *Phenology*

# Environmental limiting crop growth, development and yield

- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

# Solar Radiation and Plant Life

For plants, radiation is:

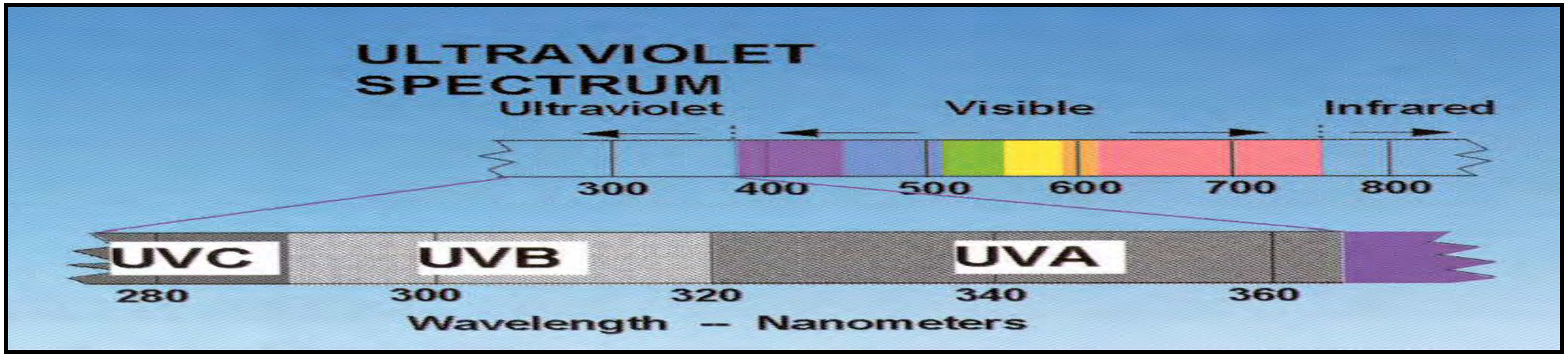
- A source of energy (photoenergetic effect).
- Stimulus for development (photocybernetic effect).
- Stress factor (photodestructive effect).

# Effects of Radiation on Plant Life

| Spectral Region | Wavelength nm | % | Photo-synthe-sis | Effects: Photo morpho-genetic | Effects: Photo destru-ctive | Effects: Thermal |
|---|---|---|---|---|---|---|
| Ultraviolet | 290-380 | 0-4 | IS | Slight | S | IS |
| PAR | 380-710 | 21-46 | S | S | Slight | S |
| Infrared | 750-4000 | 50-79 | IS | S | IS | S |
| Longwave | 4000-100000 | | IS | IS | IS | S |

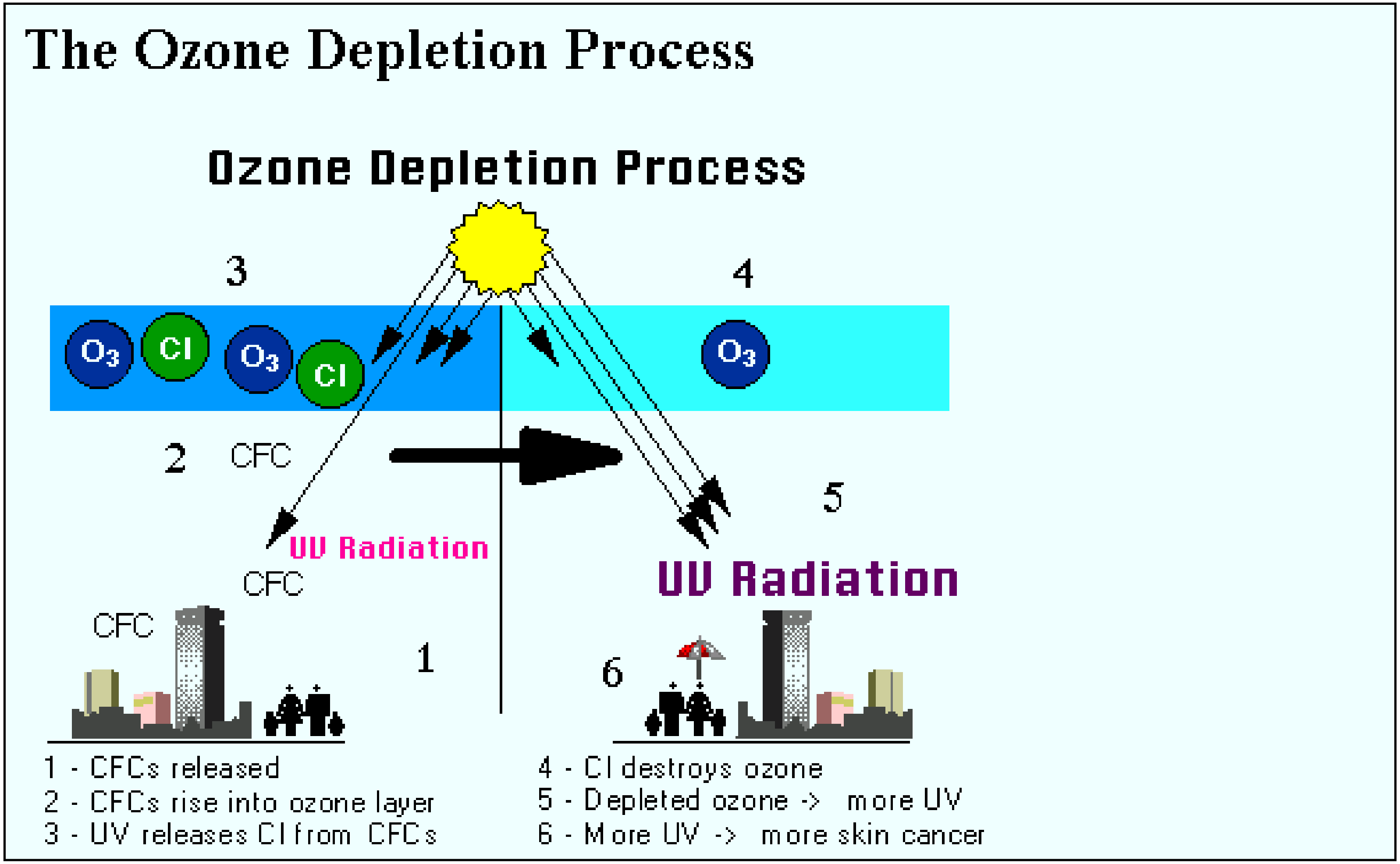
IS = Insignificant, S = Significant

# Ultraviolet Radiation

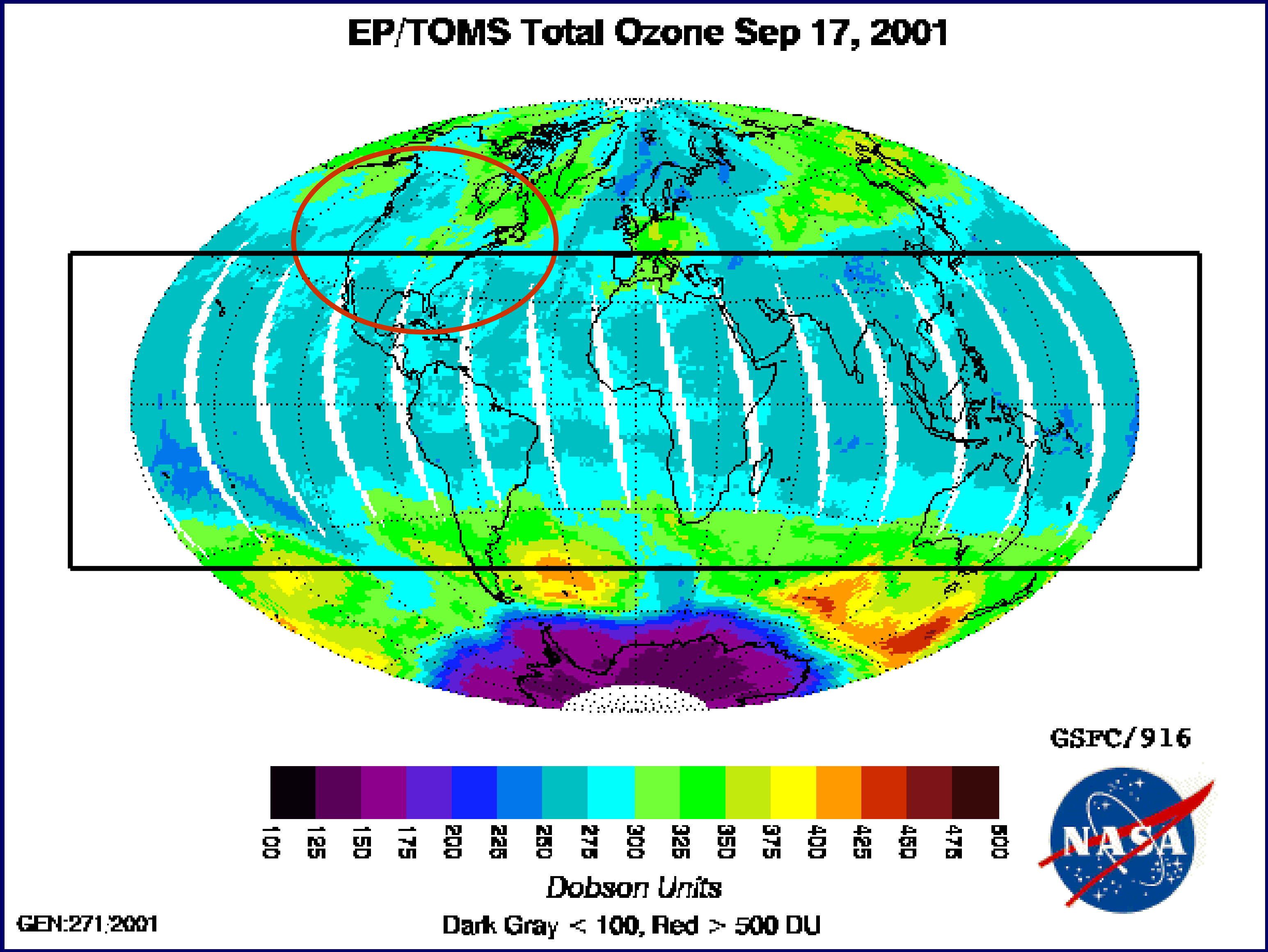



- **UVC: <280), UVB: 280-320, and UVA: 320-400.**
- UVA is not absorbed by ozone.
- UVB is mostly absorbed by ozone, although some reaches the Earth.
- UVC is completely absorbed by ozone and normal oxygen.

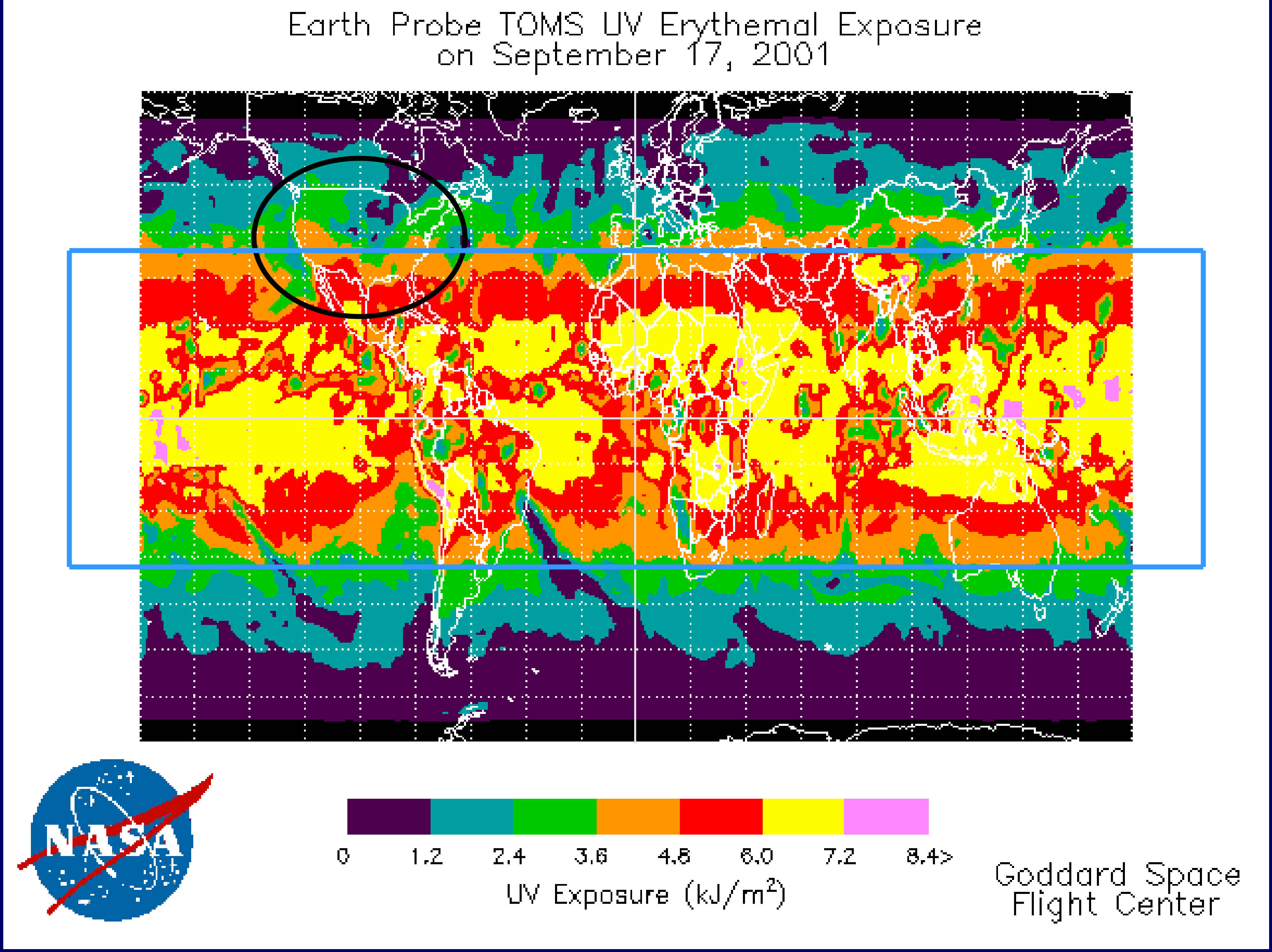
# Why are we concerned with UV now?



# Satellite Based Ozone levels - 2001

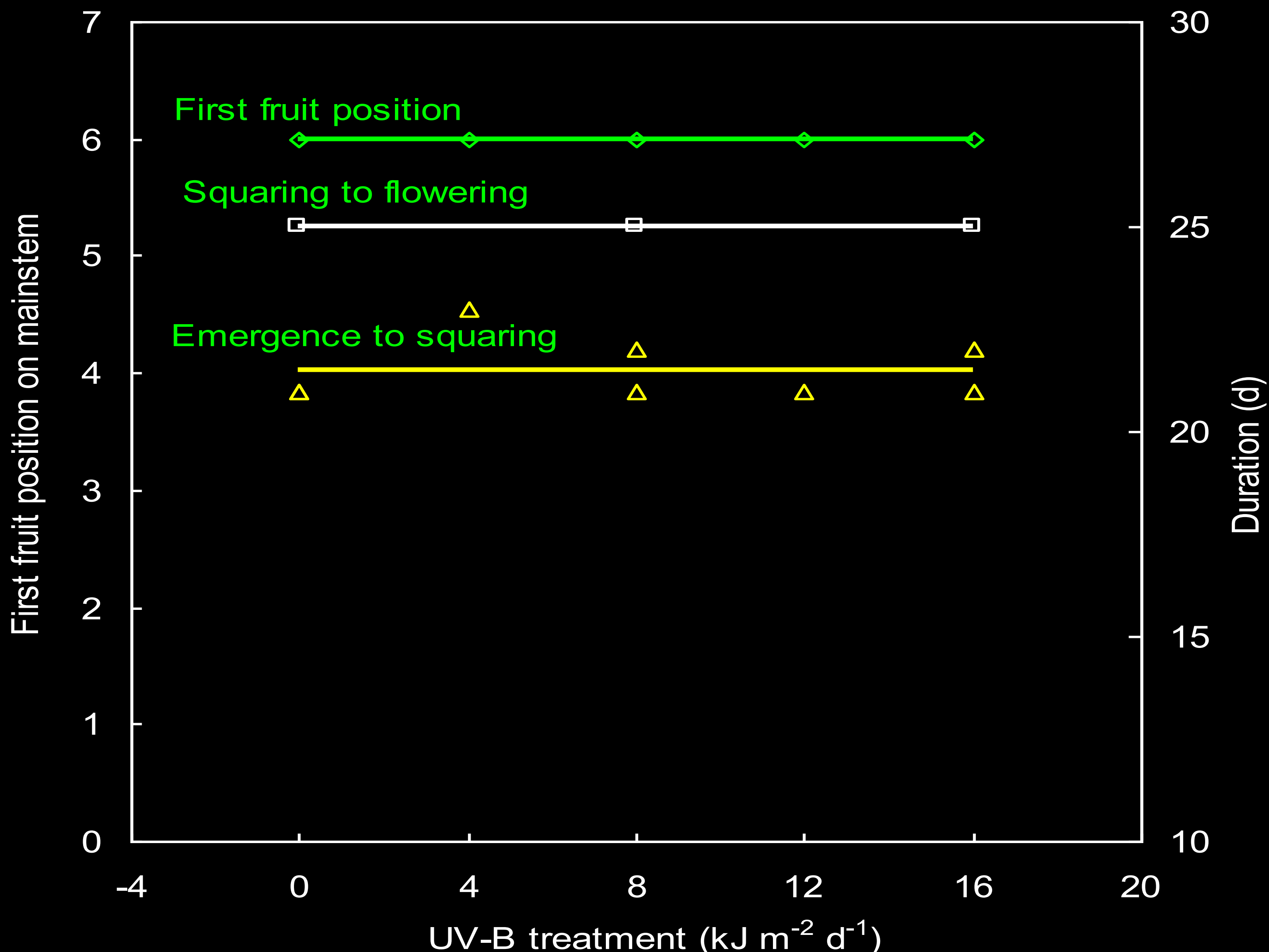


# Satellite Based UV Radiation levels - 2001



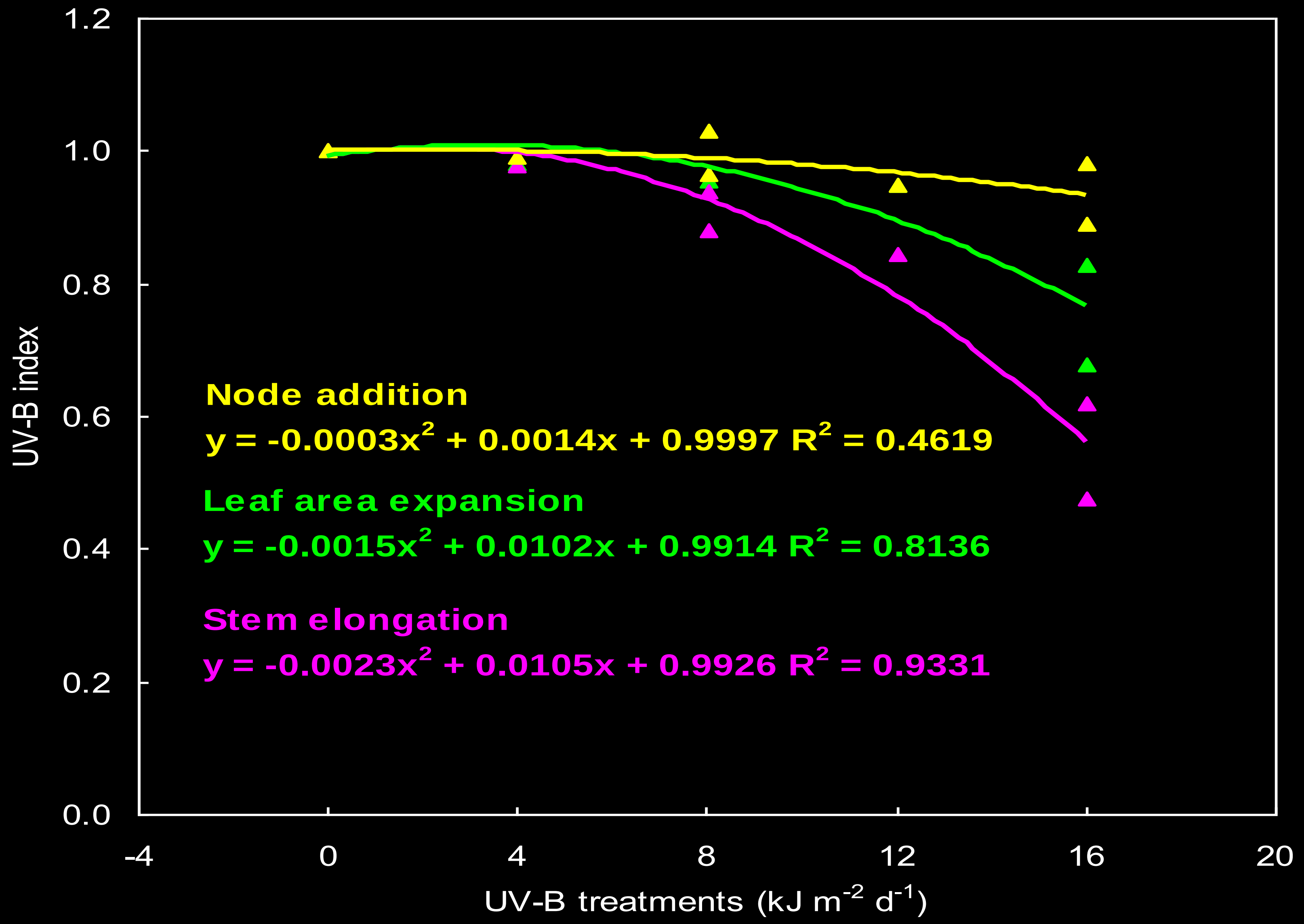
# UV-B Radiation – Growth

## EPI Factors for various growth Processes

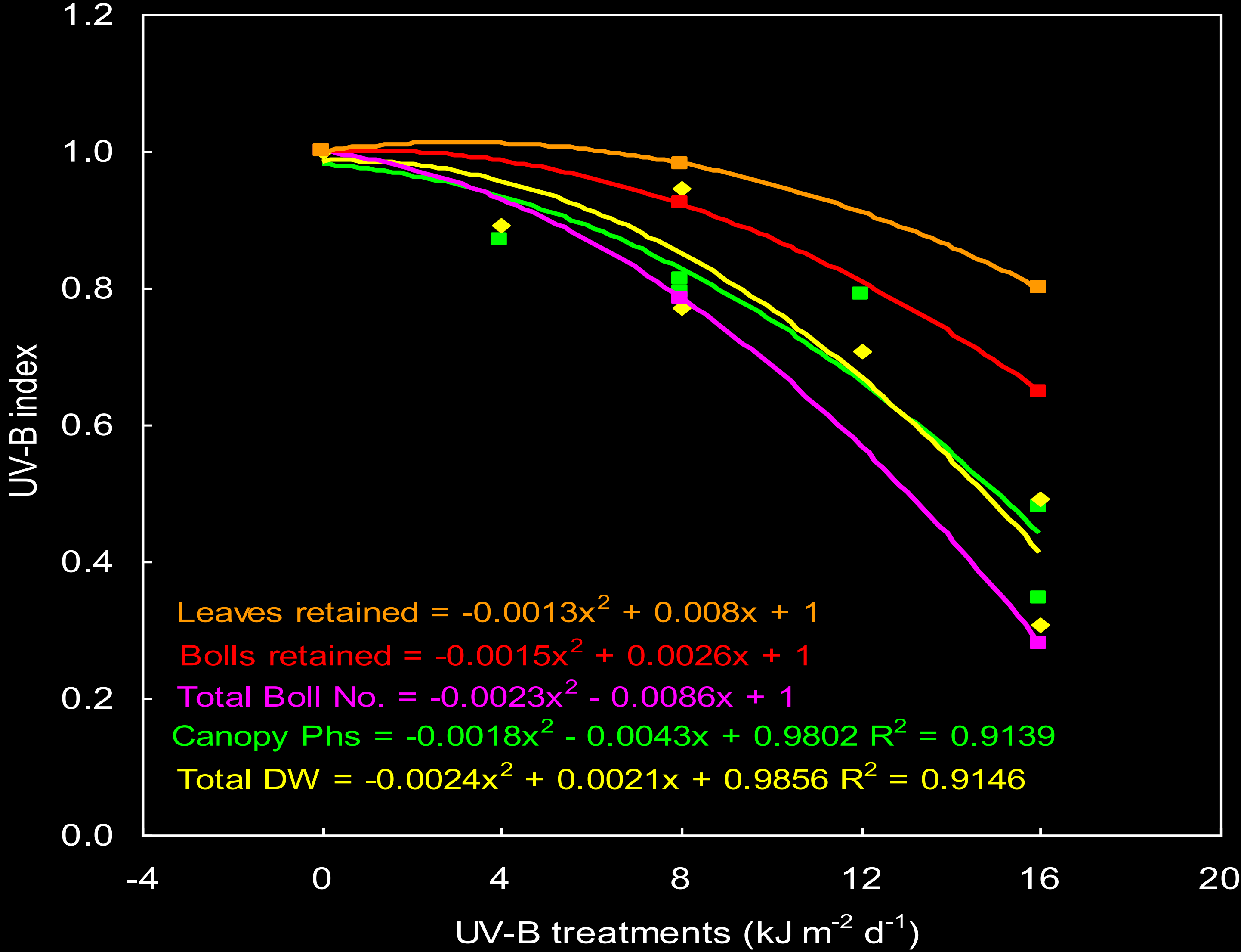


# UV-B Radiation – Phenology

## EPI Factors for various Developmental Processes



# UV-B Radiation – Cotton Growth
## EPI Factors for various growth Processes



# Environmental limiting crop growth, development and yield

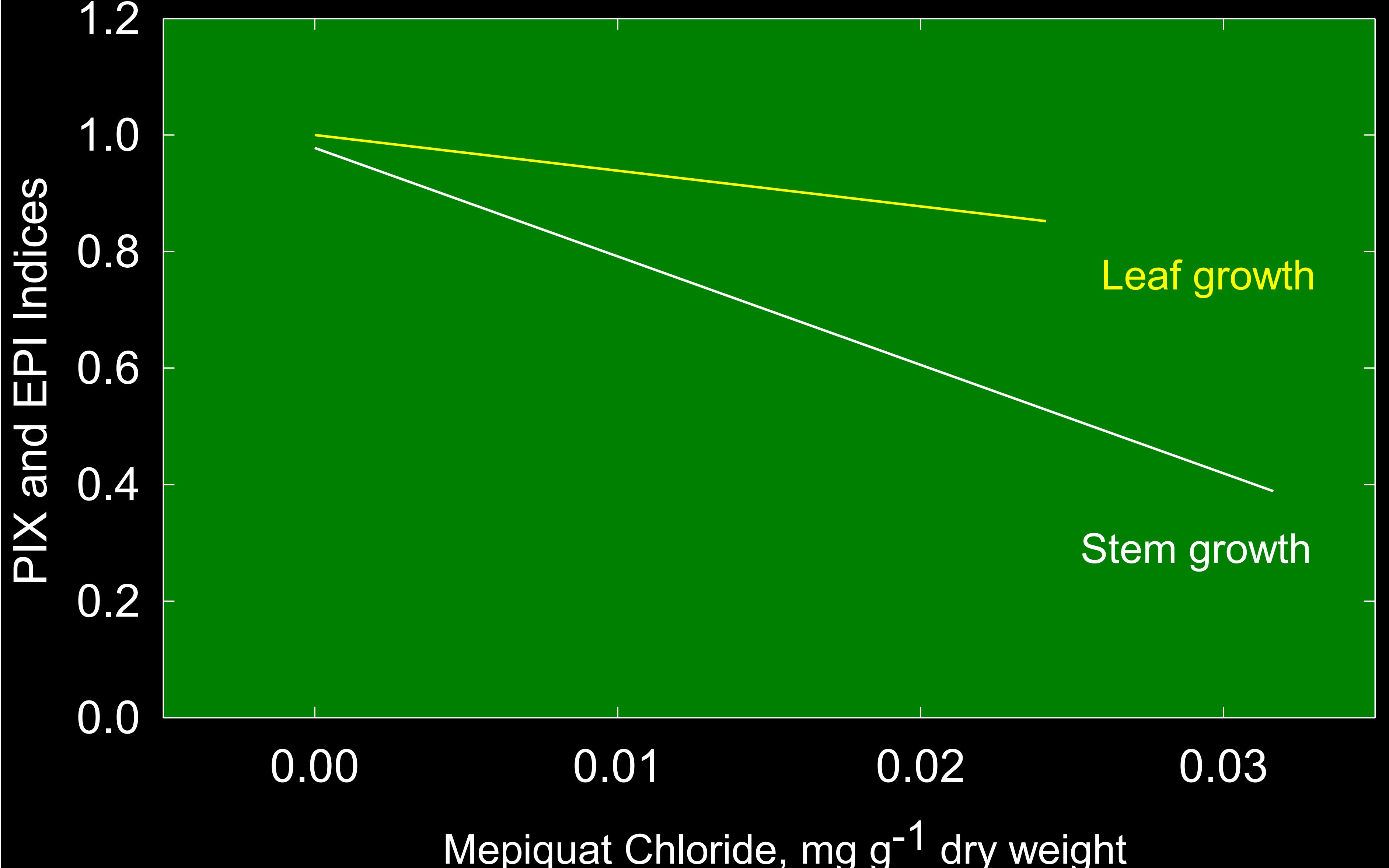
- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

# Environment Factors

Growth Regulators - Mepiquat Chloride (PIX):

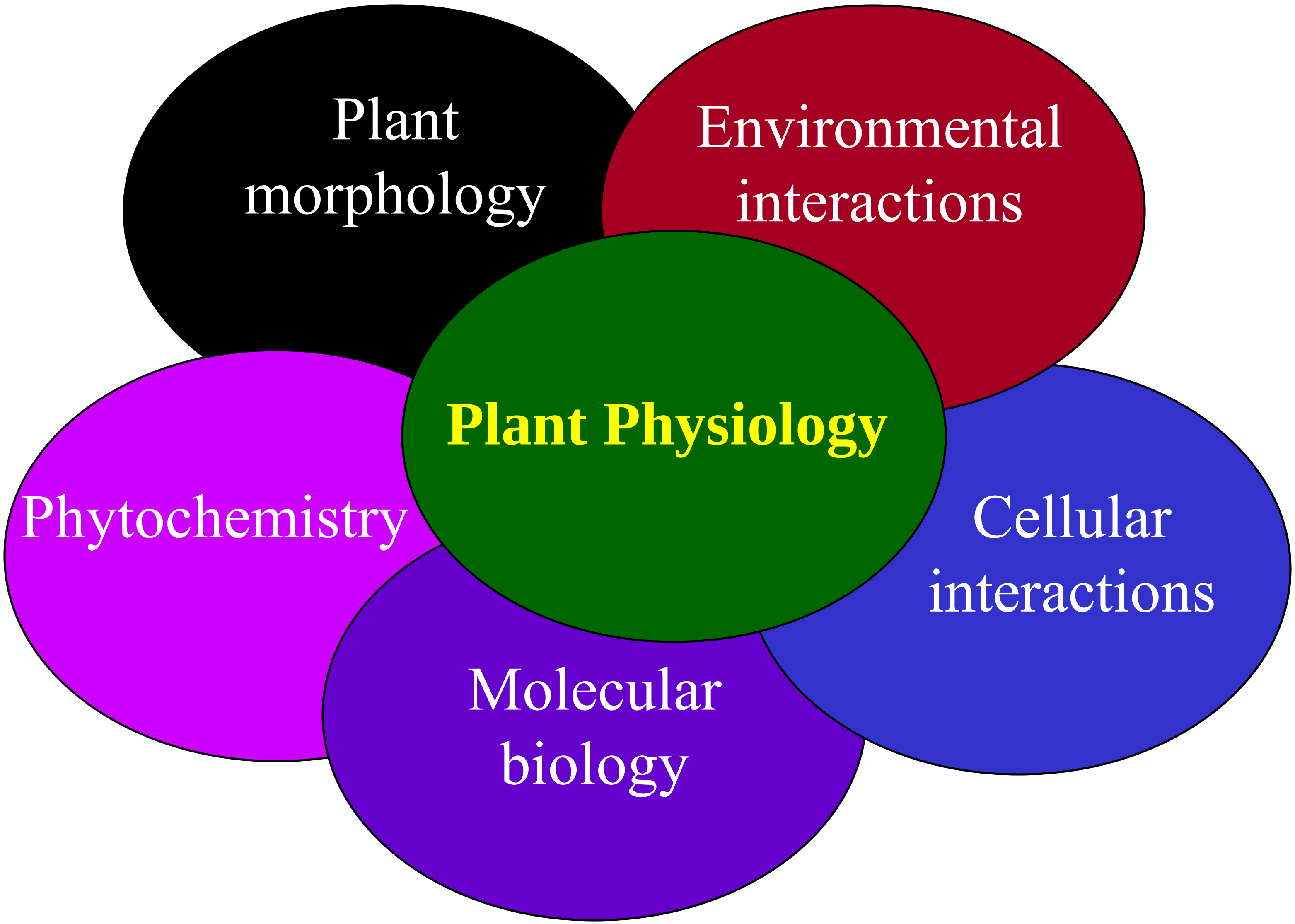
- Moderately Affects:
  -- *Leaf, stem and branch growth and LAI*
- Slightly Affects:
  -- *Photosynthesis*

# Mepiquat Chloride (PIX) - Growth
## EPI Factors

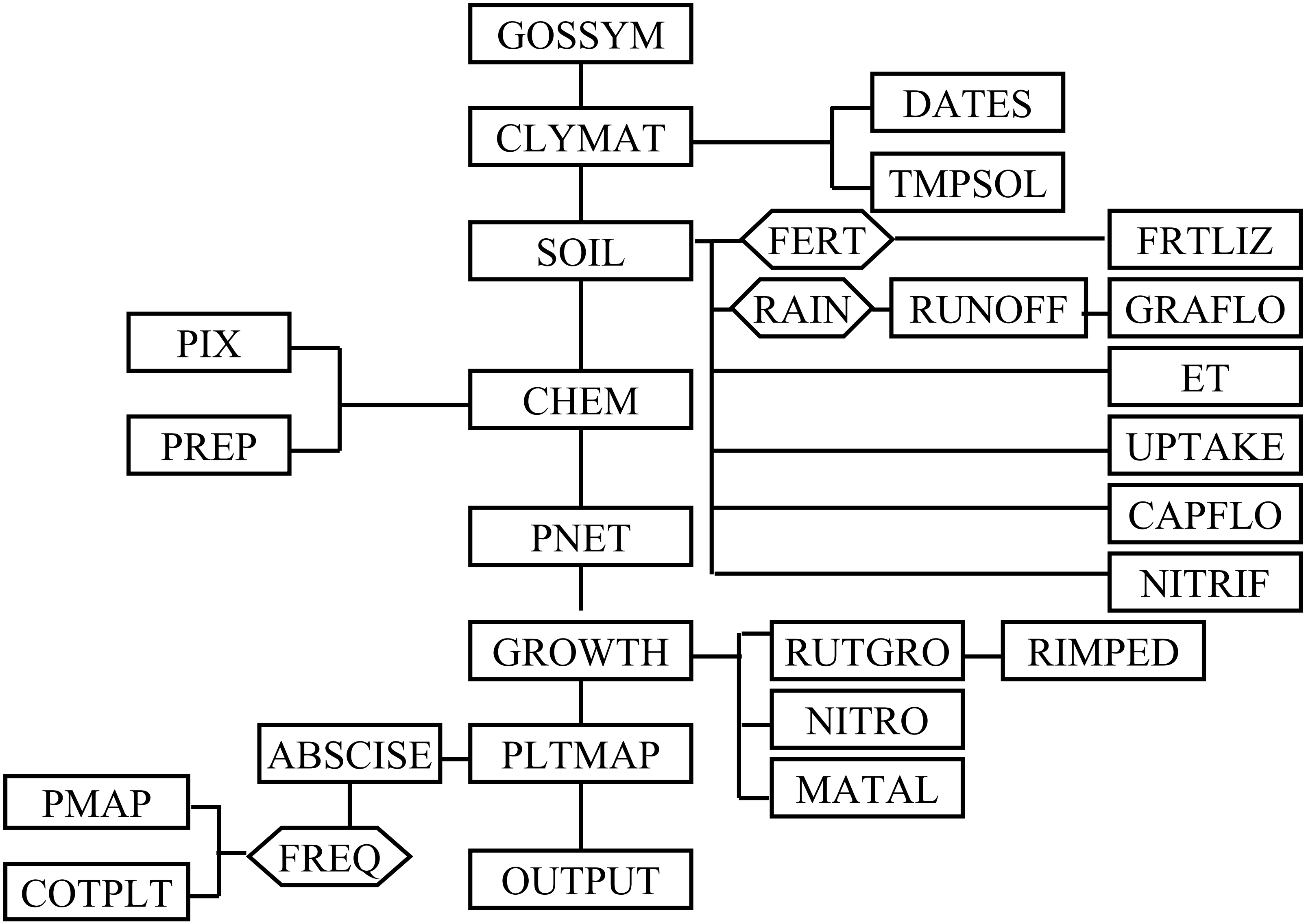


# Plants are bound and lack locomotion

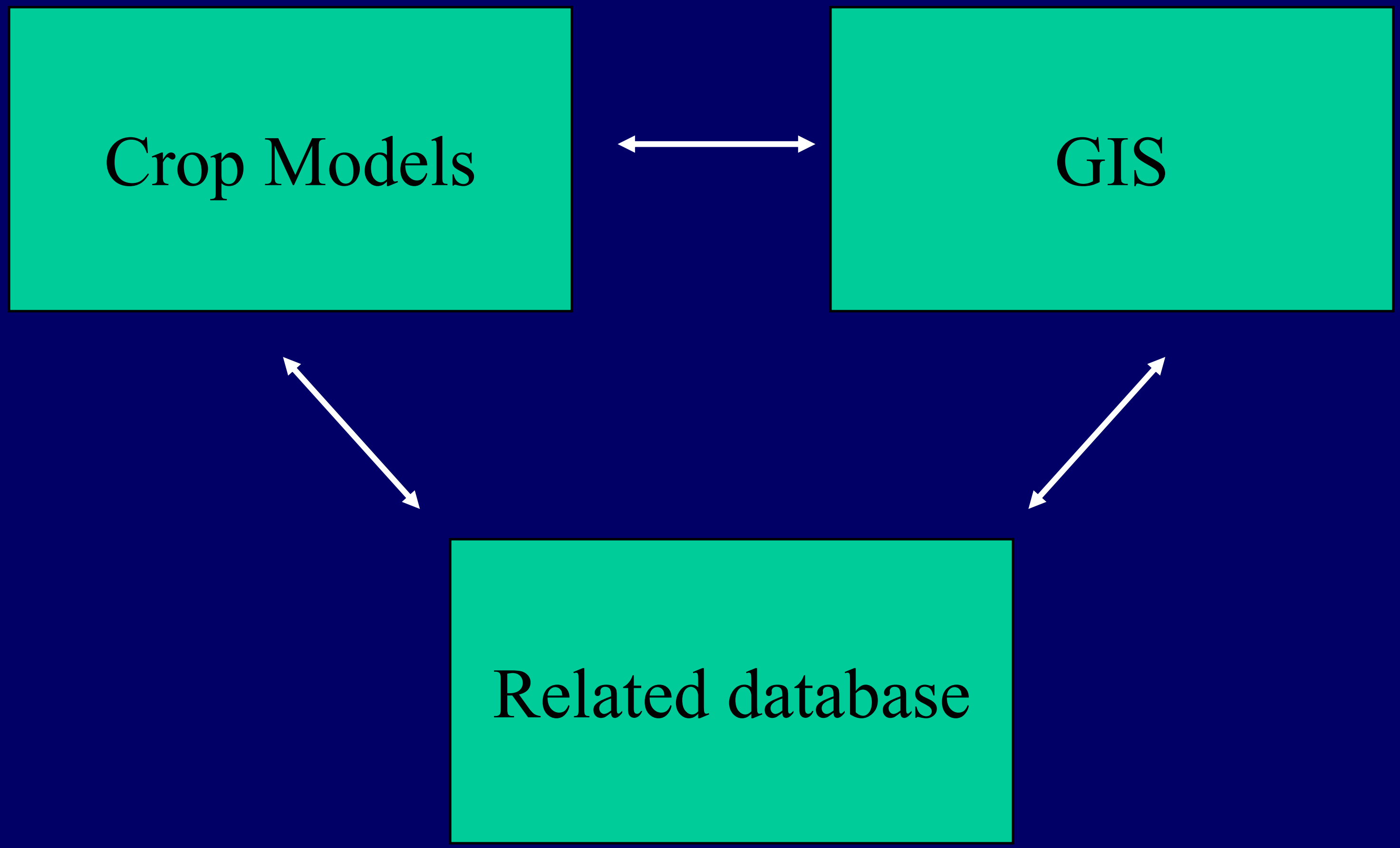
- External stress
  - Biotic
    - Infection
    - Herbivory
    - Competition
  - Abiotc
    - Temperature
      - Range - TAR
      - Heat
      - Cold
        - Chilling
        - Frost
    - Water
      - Drought
      - Flooding Hypoxia
    - Radiation
      - Solar radiation range, etc
      - UV radiation
    - Chemical
      - Minerals, Range, deficiency
      - Pollutants – Heavy metals,
      - Pesticides
      - Gases
    - Mechanical
      - Wind, Hail, Soil movement
      - Submergence
    - Other stresses
      - Electrical fields
      - Magnetic fields


Plant morphology
Environmental interactions
Plant Physiology
Phytochemistry
Cellular interactions
Molecular biology

# Flow Diagram of GOSSYM
# Cotton Crop Simulation Model



# Technology Fusion and Delivery System



# Environmental Plant Physiology and Crop Modeling

- Modeling forces the organization of known information and concepts.
- Although we may not know enough to develop a comprehensive model that includes all aspects of the farm or crop production system, modeling some meaningful portions of the system provides clarity.
- For a model to correctly predict plant responses to physical conditions, the concepts and the response functions must be appropriately assembled.

# Environmental Plant Physiology, Crop Modeling, and Technology Integration for Decision Support System

- Critical environment-genotype relations should be incorporated into the model.
- When a crop model is based on appropriate concepts and processes it will have the predictive capability in new environments, and can be used either alone or with other emerging newer technologies to disseminate useful production information.
- Also, crop models should be integrated with other related technologies for technology integration and delivery.

# Environmental Plant Physiology
# Summary and Conclusions

- To study the effects of environmental factors on growth, development and other processes, we need:
  - ✓ Controlled environmental facilities with realistic environmental conditions including solar radiation.
  - ✓ Breakdown of whole systems into sub-systems and study the influence of environmental factors on those subsystems.
  - ✓ Develop some concepts such as EPI to quantify the effects of multiple environmental factors on subsystems.
  - ✓ Integrate sub-systems into coherent whole plant/field/ecosystem system-level models/tools.

# Environmental Plant Physiology
# Summary and Conclusions

- Validated/integrated system simulation models will be useful:
  - ✓To test hypothesis.
  - ✓To understand multiple environmental effects or interactions.
  - ✓Can be used for resources management at the filed-level.
  - ✓Can be used for resource management to assist policy decisions.
  - ✓Can be used as an educational tool to understand the effects of environment/management effects on crop functioning.
  - ✓Can be used for impact assessment of climate change on cop production systems across regions and nations.

"You cannot build peace on empty stomachs."

John Boyd Orr
Nobel Peace Laureate
First FAO Director General

"You can't eat the potential yield, but need to raise the actual by combating the stresses"

Norman E. Borlaug
Nobel Peace Laureate